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Low Temperature Thermocouples: KP, "normal" silver, and copper versus Au-0.02 at% Fe and Au-0.07 at% Fe*

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The Seebeck thermoelectric voltages of two dilute alloys of iron in gold, Au 0.02 at% Fe and Au-0.07 at% Fe, have been determined with respect to KP (a particular Ni-Cr alloy), "normal" silver, and copper in the temperature range from 4 to 280 K. The power series representation of these data, along with the calculated Seebeck coefficients and derivatives of the Seebeck coefficients, have been extrapolated to 0 K and are presented as a function of temperature. In addition to these reference data, seven different Au-0.07 at% Fe alloys were thermoelectrically intercompared in order to determine the variability in wires from different melts and from different manufacturers. The largest deviation found amounted to about 9 percent of the output of a KP versus Au-0.07 at% Fe thermocouple pair between 4 and 20 K. A more typical variation for this temperature range was 2 to 4 percent. Initial indications are that the reference data can be adjusted satisfactorily with data from spot calibrations on particular wires. The effect of heat treatment is illustrated by comparing our results to Rosenbaum's data for annealed and unannealed specimens of both Au-Fe alloys.

Key Words: Cryogenics; gold alloy; liquid helium; liquid hydrogen; liquid nitrogen; thermocouples.

1. Introduction

The increasing use of liquid hydrogen and liquid helium in the scientific and aerospace communities has created a demand for specialized thermometry below, say, 25 K. Ordinary thermocouple combinations are only marginally acceptable due to their low sensitivity in this range. Dilute alloys of noble metals and transition metals, however, do form thermoelements with relatively high temperature sensitivity below 25 K. Au-2.1 at% (atomic percent) Co is perhaps the best known of this type. Unfortunately, the Au-Co alloy forms a supersaturated solid solution; Co tends to migrate to the grain boundaries even at room temperature [1][1]. This migration changes the thermoelectric properties and reduces the worth of this material as a thermoelement. Another family of alloys of this type are alloys of Fe in Au. These alloys are metallurgically stable and exhibit extremely useful thermoelectric properties at very low temperatures. Work recently completed at the National Bureau of Standards in Boulder has resulted in precise calibrations and intercomparisons of two of these alloys, Au-0.02 at% Fe and Au-0.07 at% Fe. Our primary emphasis has been directed to the latter alloy. A differential thermocouple made with either of these Au-Fe alloys as the negative element and copper, "normal" silver (Ag-0.37 at% Au), or KP[2] as the positive element provides a usable sensitivity even below 4 K.

The fact that trace amounts of transition elements in noble metal solvents causes anomalous thermoelectric properties has been known for some time. Borelius [2, 3] and co-workers determined the thermoelectric sensitivity of many dilute alloys of copper, silver, gold, and platinum in 1932. The electrical resistivity and thermopower of these alloys are of interest because of the unusual electron scattering which must be present to cause the peculiar behavior. Much of the work done on dilute alloys has, therefore, been to understand the bulk transport properties involved. Development of the Au-Fe alloys for use in low temperature thermocouple thermometry didn't really begin until after 1960 when Berman [4] tested Au-0.02 at% Fe for possible use in their thermal conductivity apparatus. Since that time others, including ourselves, have been drawn into the field in search of better thermometers for use in thermal conductivity measurement systems.

Several necessary thermoelectric properties have been determined for the Au-Fe alloys, e.g., reproducibility after repeated thermal cycling [5], behavior in a

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[1] Figures in brackets indicate the literature references at the end of this paper.

[2] KP is the ASTM and ISA designation for a 90% Ni+10% Cr alloy. Trade names for this material are: Chromel, Hoskins Manufacturing Co.; Tophel, Wilbur B. Driver Co.; T–1, Driver-Harris Co.; and Thermo Kanthal KP, Kanthal Corp. Use of trade names does not constitute an endorsement of any manufacturer's products.

magnetic field [6], and the effect of heat treatment [7, 8]. The number of investigations concerning these properties is small and the conclusions could, therefore, be representative of particular materials rather than a general material. The consensus is, however, that sufficient information is available to establish the Au-Fe alloys as the most promising thermoelement available for use at very low temperatures.

The intent of our work is to provide a precise, full range calibration for several practical thermocouple combinations involving Au-Fe alloys and to present comparison data from different manufacturers, different melts, and different spools. It is hoped that the tabular data presented in this paper can be used as reference data.

Discussion of the procedures needed to adjust the reference data to individual thermocouples must be delayed. Further analysis of our data may make such information available. The brief discussion of figure 5 in the text is an indication of what we hope the more detailed analysis will show.

2. Experimental Procedure

A detailed description of the items in this section appears in NBS Monograph 124 [9]. The contents of this section will, therefore, be general and brief.

The cryostat used in the experimental work consists basically of two working chambers. One chamber is filled with a cryogen which serves as the reference temperature for the thermocouples while the second chamber is controlled to some selected higher temperature. The thermal insulation surrounding the two working chambers consists of various radiation shields, high vacuum, and finally a liquid nitrogen shield. This arrangement allows the reference temperature to be established with liquid helium (approximately 4 K), liquid hydrogen (approximately 20 K), or liquid nitrogen (approximately 75 K). In the course of a calibration the temperature ranges spanned using these reference temperatures are 4 to 25 K, 20 to 90 K, and 75 to 290 K. Figure 1 shows schematically how the thermocouple wires are situated in the system.

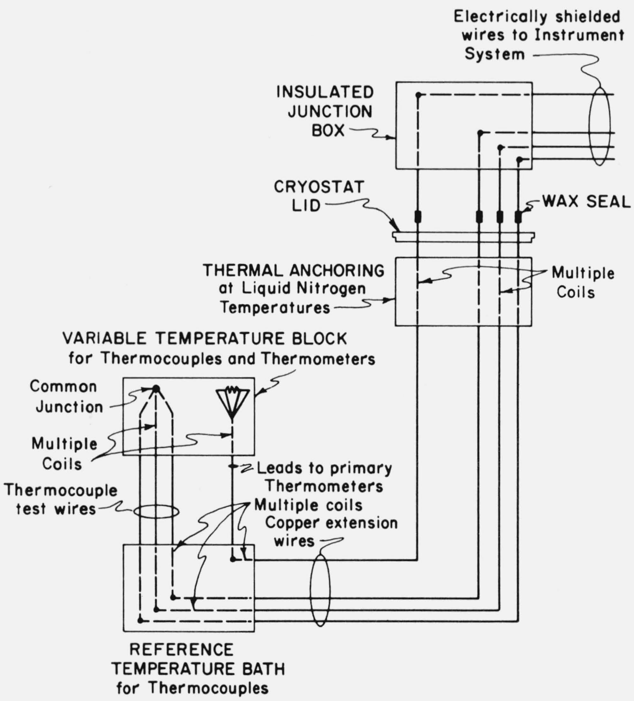

FIGURE 1. *Schematic of electrical and thermal situation of wires in the thermocouple calibration system.*

The temperature of the reference bath is determined with a platinum resistance thermometer (PRT) when either liquid hydrogen or liquid nitrogen are used as the reference cryogen. The vapor pressure of the liquid helium is used to determine the reference temperature when helium is used as the reference liquid. The variable temperature of the upper chamber is determined with a germanium resistance thermometer (GeRT) when the temperature is below 20 K and a PRT when the temperature is above 20 K. All PRT resistances are measured with a Mueller G2 bridge and all voltage readings are made on a potentiometer with a resolution of 0.01μV. All automatic temperature controllers are of in-house design. During the course of a one hour test the temperature difference between the variable and reference junctions of the thermocouples is held constant to within 5 mK.

3. Materials

The calibration system can accommodate up to 22 thermocouple test wires at one time. Two different sets of materials have been tested as part of the thermocouple thermometry program at NBS. The first set of materials contained only one Au-0.07 at% Fe wire and one Au-0.02 at% Fe wire. These two wires were thermoelectrically compared to KP, "normal" silver, and copper at a total of 68 different temperature gradients. The second set of wires to be tested contained seven different Au-0.07 at% Fe wires and one Au-0.02 at% Fe wire. In this calibration KP was compared to all of the Au-Fe specimens and the Au-0.07 at% Fe wires were intercompared. Table 1 contains additional information on the selection of samples used in both the first and second calibrations.

The KP wires used in the first and second calibrations were adjacent lengths from the same spool; dip tests indicate that there is no observable difference between adjacent lengths of wire from this particular spool. These two lengths will be referred to as the same wire for the remainder of the paper. The primary variability between the first and second calibrations involving KP must, therefore, be attributed to differences in the Au-0.07 at% Fe wires.

One of the seven wires in the second set of materials had completely different properties than the remaining six specimens. Spectrographic analysis indicated about 0.45 at% Fe rather than 0.07 at% Fe. Data obtained for this wire are not considered in the remainder of this paper or listed in table 1.

A micrograph was made for Au-0.07 at% Fe_{47} used in the first calibration (subscripts indicate specimen

TABLE 1. *Specimens of Au-0.07 at% Fe and Au-0.02 at% Fe calibrated with the first and second sets of low temperature thermocouple materials*

Alloy	Specimen number	Wire diameter (millimeters)	Comments	
Au-0.07 at% Fe...	5	0.152	Supplier 1	
	6	.152	1	
	7	.152	1	
	47	.152	1	
	10	.127	Supplier 2	Bar 1
	11	.127	2	Bar 2
	8	.254	2	Bar 1
Au-0.02 at% Fe...	45	.127	Supplier 2	Bar 1
	12	.127	Supplier 2	Bar 2

number as in table 1). Rather large grains were observed to be preferentially oriented along the axis of the wire. The maximum grain size encountered was approximately 300×70 μm.

As indicated in table 1, several different melts from two companies are represented. An important part in establishing the usefulness of Au-Fe alloys as thermocouple materials is the degree of uniformity among melts and among different producers. The results presented in the next section indicate the spread or nonuniformity found in the specimens available to us at the time of testing.

4. Results

The range of thermal voltages obtained by comparing a single KP wire to the seven Au-0.07 at% Fe wires listed in table 1 is shown in figure 2. The band in this figure is determined by plotting data for the combinations having the highest and lowest output of the KP versus Au-0.07 at% Fe pairs tested. Since the band width in this figure results from different Au-0.07 at% Fe wire versus the same KP wire, the observed spread in the data must be due to variation in the Au-0.07 at% Fe materials. Thermoelectric differences among the seven Au-0.07 at% Fe specimens are made more clear when the contribution of the KP element is eliminated as in figure 3. The data in this figure represent experimentally determined differences among the Au-0.07 at% Fe specimens except for the specimen 5 versus specimen 47 curve which is calculated.[3] The variations in the Au-0.07 at% Fe material are compared with the total output of the KP versus Au-0.07 at% Fe combination in table 2. Specimen 11 is used as the common Au-0.07 at% Fe wire in this table. The largest relative deviations are seen to be in the temperature range 4 K to 20 K; this is the same temperature range where the enhanced sensitivity is needed. Rosenbaum [7] compared different melts of Au-0.07 at% Fe from a single manufacturer and found voltage variations of 1.4 percent between 4.2 K and 77 K and 1.9 percent between 4.2 K and 273.2 K. These values appear reasonable when compared to the corresponding data for our wires given in table 2. It is interesting that wire 5 and

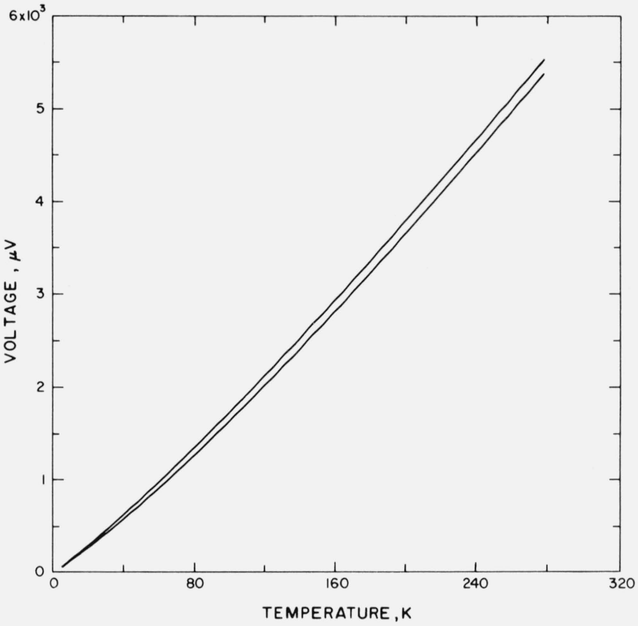

FIGURE 2. *Extremes of the thermoelectric voltage found in tests paring a single KP wire to seven different Au-0.07 at% Fe wires.*

wire 7, figure 3, are from the same company; within company variations are greater than intercompany variations for our limited selection of specimens. The general grouping in figure 3, however, indicates that the variation between wires 6 and 7 is more typical of the within company differences. The near identity of wires 10 and 11 is undoubtably fortuitous since wire 8 is from the same melt as wire 10.

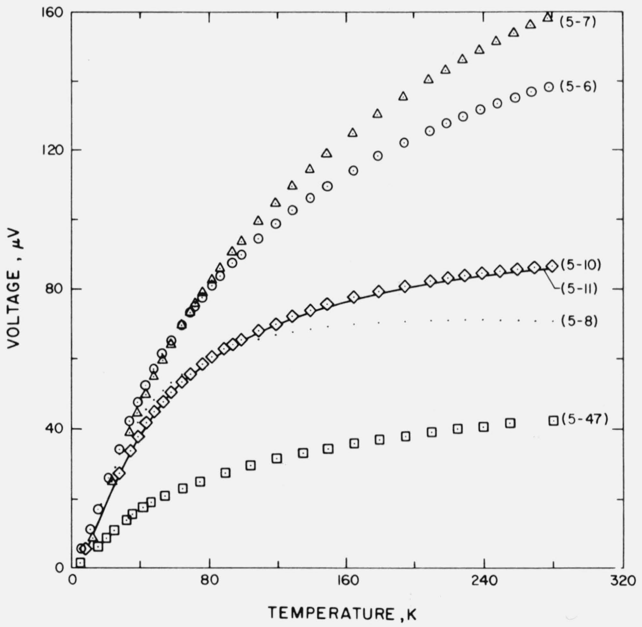

FIGURE 3. *Experimentally determined thermoelectric differences between Au-0.07 at% Fe_5 and the other six Au-0.07 at% Fe specimens.*

The numbers in parentheses represent the specimen numbers involved in the individual curves.

[3] Many experimental points have been omitted from the NBS curves throughout this paper in order to reduce the cluttered appearance of the point graphs. All experimental data were, however, used to determine the proper analytical representation and tables to be given later.

TABLE 2. *Voltage differences between Au-0.07 at% Fe_{11} and the remaining Au-0.07 at% Fe specimens and percentage variation of the thermoelectric voltage of each KP versus Au-0.07 at% Fe pair from the thermoelectric voltage of KP versus Au-0.07 at% Fe_{11}*

Au-0.07 at% Fe	Temperature Range 4–20 K		4–75 K		4–280 K		20–75 K		20–280 K		75–280 K	
Specimen numbers	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)	$\Delta E \mu V$	$\Delta E/E \times 100$ (percent)
5 vs 11	15.99	6.3	55.31	4.7	84.07	1.6	39.32	4.2	68.08	1.3	28.76	0.7
11 vs 6	4.00	1.6	16.89	1.4	49.53	0.9	13.79	1.5	46.43	0.9	32.64	.8
11 vs 7	1.69	0.7	20.21	1.7	72.05	1.3	18.52	2.0	70.36	1.4	51.84	1.2
11 vs 10	0.07	.0	0.10	0.0	0.11	0.0	0.03	0.0	0.04	0.0	0.01	0.0
8 vs 11	3.13	1.2	.93	.1	16.19	.3	2.20	.2	19.32	.4	17.12	.4
47 vs 11	8.18	3.2	31.28	2.6	43.00	.8	23.10	2.5	34.82	.7	11.72	.3
Average	5.51	2.2	20.79	1.8	44.16	.8	16.16	1.7	39.84	.8	23.68	.6

Figure 4 contains the Seebeck coefficients for the KP versus Au-0.07 at% Fe thermocouple pairs tested. The close grouping of specimens 6, 7, 8, 10, and 11 is apparent here as well as the outlying characteristics of specimen 5. Table 3 details the temperatures and sensitivities at the low temperature inflections. Figure 5 plots Seebeck coefficients for three KP versus Au-0.07 at% Fe pairs. The lower line plot in this figure is for the single KP versus Au-0.07 at% Fe_{47} from the first set of calibrations. The data for this KP versus Au-0.07 at% Fe combination has not been published, but it has been rather widely distributed. The data represented by the higher of the two line curves are for KP versus Au-0.07 at% Fe_7. The third curve, represented by rectangles, results when the data for KP versus Au-0.07 at% Fe_{47} in this figure is adjusted by dip test data for a length of wire adjacent to specimen 7. The KP used in the dip tested thermocouple was from a different manufacturer than that used to determine KP versus Au-0.07 at% Fe_{47}. A detailed thermoelectric comparison had been made earlier for the two KP materials involved; there was no observable difference when the temperature was below 80 K and above 80 K there was a linear divergence to about 10μV when the temperature was 280 K. The lined data result from two separate and complete calibrations in the thermocouple calibration apparatus. There was approximately a three year time lapse between the calibrations. The rectangular data, on the other hand, resulted when information obtained from a series of dip tests was used to adjust the lower lined data.

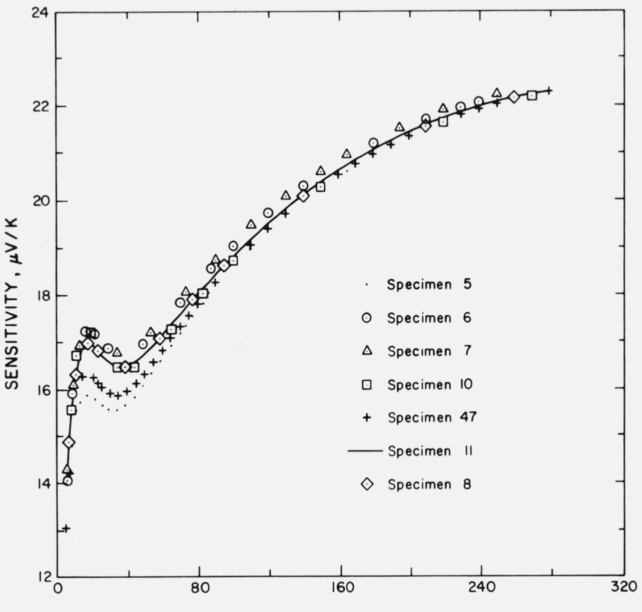

FIGURE 4. *Calculated Seebeck coefficients for a single KP wire versus seven specimens of Au-0.07 at% Fe.*

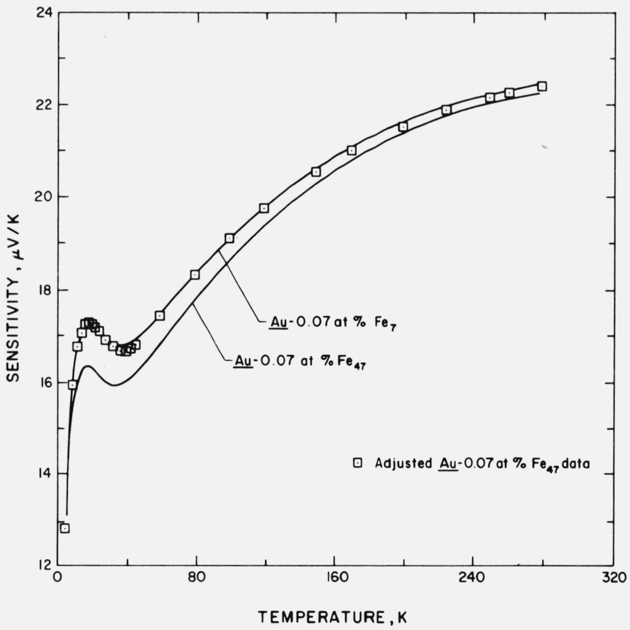

FIGURE 5. *Comparison of Seebeck coefficients for KP versus Au-0.07 at% $Fe_{7,47}$ and the Seebeck coefficient for KP versus Au-0.07 at% Fe_7 computed by applying dip test data to the KP versus Au-0.07 at% Fe_{47} data.*

TABLE 3. *Temperatures and corresponding Seebeck coefficients for the low temperature inflection points in the KP versus Au-0.07 at% Fe data*

Au-0.07 at% Fe Specimen number	Low temperature maximum		Low temperature minimum	
	T(K)	$S(\mu V/K)$	T(K)	$S(\mu V/K)$
5..................................	17.8	15.84	32.3	15.53
6..................................	18.1	17.23	37.1	16.71
7..................................	18.8	17.21	36.5	16.79
8..................................	17.3	17.14	38.6	16.43
10................................	18.1	16.99	37.3	16.45
11................................	18.0	17.00	37.3	16.45
47................................	17.2	16.36	34.2	15.91
Average................	17.9	16.82	36.2	16.32
Estimate of σ........	0.54	0.53	2.2	0.45

Heat treatment of the Au-0.07 at% Fe material is critical as is shown in figure 6. The point curves by Rosenbaum [7] represent data from the same bar stock before and after annealing. The thermopower is enhanced by annealing as would be expected when physical defects are eliminated. The Seebeck coefficient for KP versus Au-0.07 at% Fe_{11} is shown as a line in this figure. Rosenbaum's experimental data for KP versus Au-0.07 at% Fe extends down to about 1.3 K, while the lower limit for our experimental data is approximately 5 K. The Seebeck coefficients plotted in figure 7 represent data for KP versus specimens of Au-0.02 at% Fe used in the first and second calibrations and for Rosenbaum's [7] annealed and hard worked specimens. Specimen 12, used in the second calibration, was annealed by the supplier while specimen 45, used in the first calibration, was annealed in-house at 350 °C for 20 minutes in air. It appears that the in-house anneal may have been more effective than the producer anneal on our specimen 12. Rosenbaum's data for KP versus Au-0.02 at% Fe extends down to 0.437 K for the hard drawn specimen. Figures 8 and 9 are further comparisons of our results of those of Rosenbaum. In particular, copper versus Au-0.07 at% Fe_{11} is compared to Rosenbaum's results [8] for copper versus annealed Au-0.07 at% Fe in figure 8 and copper

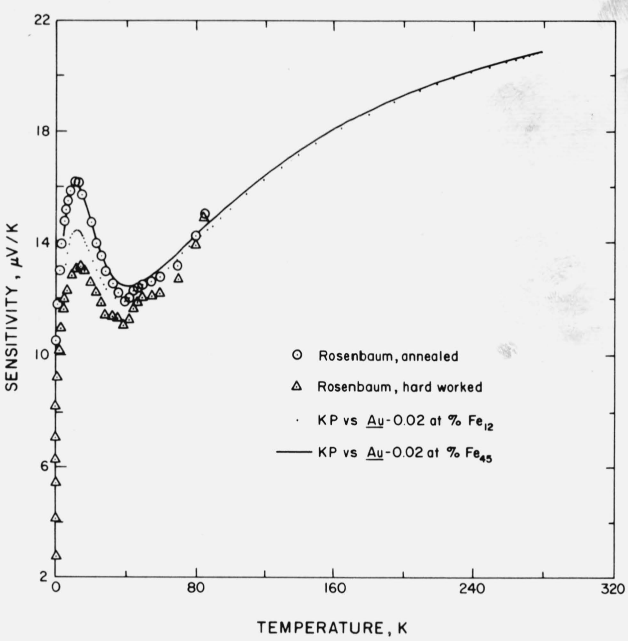

FIGURE 7. *Comparison of Seebeck coefficients for KP versus Au-0.02 at% Fe in the annealed and unannealed state.*

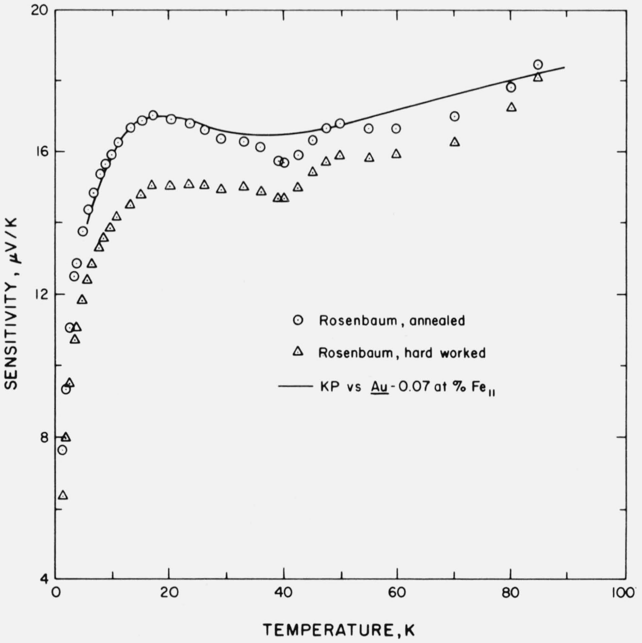

FIGURE 6. *Comparison of Seebeck coefficients for KP versus Au-0.07 at% Fe in the annealed and unannealed state.*

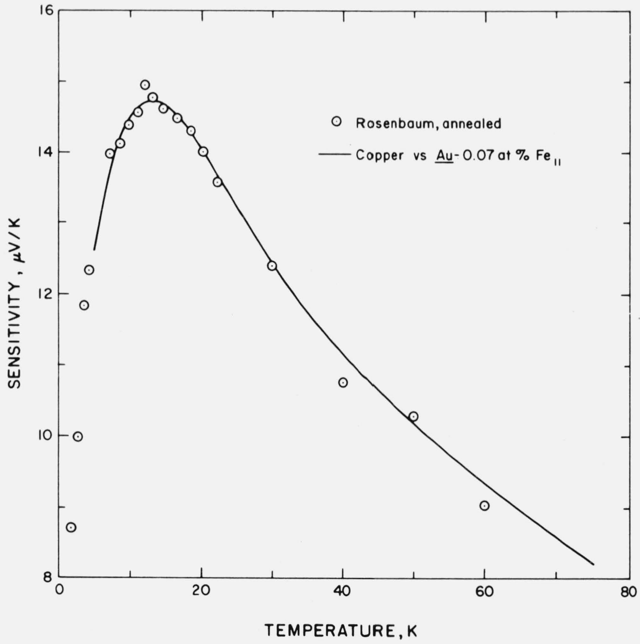

FIGURE 8. *Seebeck coefficients for copper versus Au-0.07 at% Fe.*

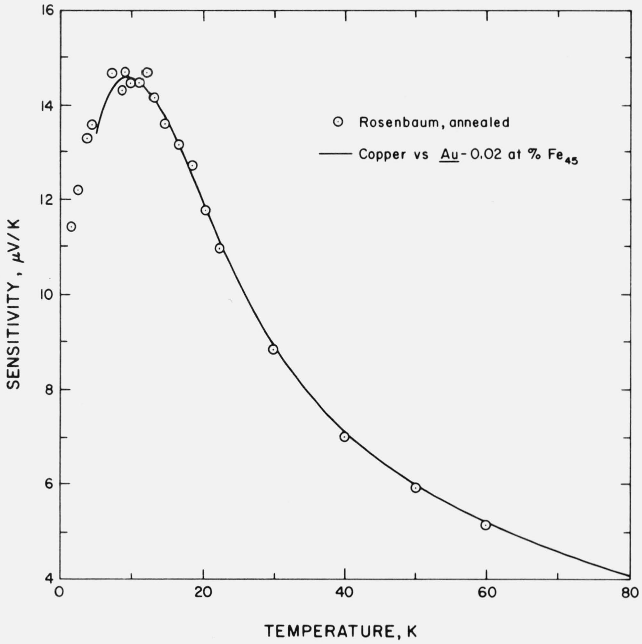

FIGURE 9. *Seebeck coefficients for copper versus* Au-0.02 *at%* Fe.

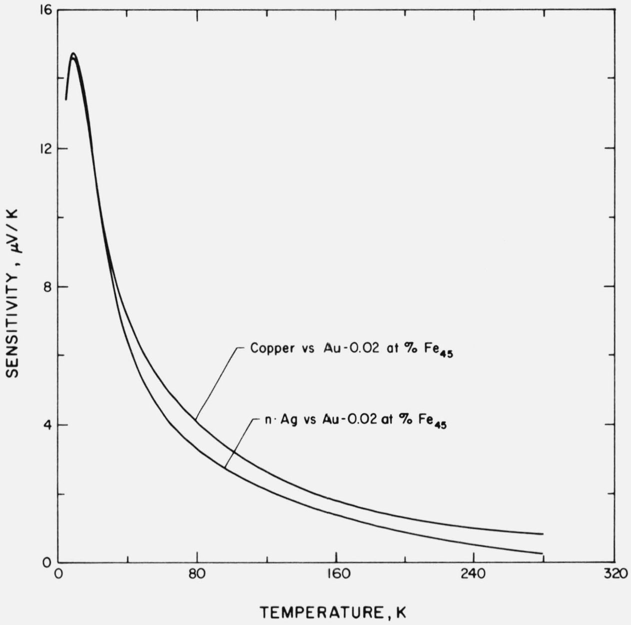

FIGURE 11. *Seebeck coefficients for copper and "normal" silver versus* Au-0.02 *at%* Fe_{45}.

versus Au-0.02 at% Fe_{45} is compared to Rosenbaum's results for copper versus annealed Au-0.02 at% Fe in figure 9. Figures 10 and 11 show the Seebeck coefficients for copper and "normal" silver versus Au-0.07 at% Fe_{11} and Au-0.02 at% Fe_{45}, respectively. The effect of KP in the thermoelectric circuit with the Au-Fe alloys is clear when the rapidly falling thermopowers in figure 10 are compared with the thermopowers shown in figure 4.

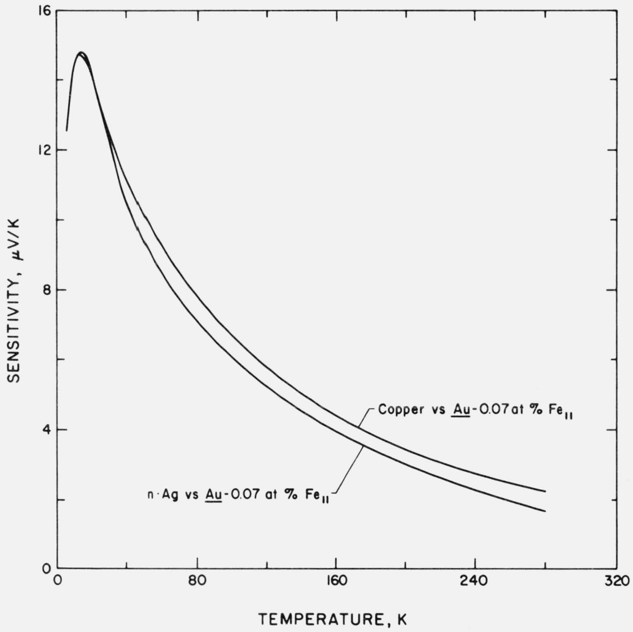

FIGURE 10. *Seebeck coefficients for copper and "normal" silver versus* Au-0.07 *at%* Fe_{11}.

A modified Gram-Schmidt approximation [10, 11] was used to represent the experimental data. Details of the fitting procedure are discussed elsewhere [9]. In order to facilitate computer programming of the data the original orthonormal polynomials and the associated orthonormal polynomial coefficients have been recombined to give simple power series coefficients. The relationship between temperature in degrees kelvin and the Seebeck voltage in microvolts for thermocouple types KP, copper, and "normal" silver versus Au-0.02 at% Fe_{45} and Au-0.07 at% Fe_{11} are represented by

$$E(T)=\sum_{n=1}^{L} B_nT^n.$$

The coefficients, B_n, for the above thermocouple combinations are listed in table 4. Tables 5 through 10 are tabular results of the power series representation for one degree intervals in temperature. The Seebeck coefficients and their derivatives are also given in these tables. The experimental basis for the data is $5 \leq T \leq 280$ K. Any extension of the power series representation for $T > 280$ K is an extrapolation and all of the uncertainties inherent in such extensions of experimental data must apply. Extension of the data to $T < 5$ K is more acceptable since the constraint $E = 0$ μV when $T = 0$ K was used in the original fit.

A detailed error analysis has been done for the thermocouple calibration system and is discussed in the previously mentioned monograph [9]. A similar analysis of the Au-Fe combinations result in the total uncertainties given in table 11. These uncertainties include random errors and estimates of systematic errors, but are exclusive of errors in the temperature

TABLE 4. *Power series coefficients for thermocouple types KP versus* Au-0.07 *at%* Fe, KP *versus* Au-0.02 *at%* Fe, *copper versus* Au-0.07 *at%* Fe, *copper versus* Au-0.02 *at%* Fe, *normal silver versus* Au-0.07 *at%* Fe, *and normal silver versus* Au-0.02 *at%* Fe.

Power series coefficients	KP vs Au 7 Fe	KP vs Au 2 Fe	Cu vs Au 7 Fe	Cu vs Au 2 Fe	n. Ag vs Au 7 Fe	n. Ag vs Au 2 Fe
B(1)................	6.9864426367	7.2668579396	6.9819441789	7.2623594676	6.9616414011	7.2420566898
B(2)................	$9.0607276605 \times 10^{-1}$	1.0692244345	$8.4001378651 \times 10^{-1}$	1.0031654569	$8.1796982011 \times 10^{-1}$	$9.8112149062 \times 10^{-1}$
B(3)................	$-4.3469694773 \times 10^{-2}$	$-6.2220191022 \times 10^{-2}$	$-4.5417070202 \times 10^{-2}$	$-6.4167566583 \times 10^{-2}$	$-4.1183301479 \times 10^{-2}$	$-5.9933797876 \times 10^{-2}$
B(4)................	$1.2468246660 \times 10^{-3}$	$1.9487031660 \times 10^{-3}$	$1.3796048892 \times 10^{-3}$	$2.0814833941 \times 10^{-3}$	$1.1332864853 \times 10^{-3}$	$1.8351649913 \times 10^{-3}$
B(5)................	$-2.3500537590 \times 10^{-5}$	$-3.8863862277 \times 10^{-5}$	$-2.7648679333 \times 10^{-5}$	$-4.3012004132 \times 10^{-5}$	$-2.0564116972 \times 10^{-5}$	$-3.5927441812 \times 10^{-5}$
B(6)................	$3.0837610415 \times 10^{-7}$	$5.3284892976 \times 10^{-7}$	$3.8534874955 \times 10^{-7}$	$6.0982157678 \times 10^{-7}$	$2.6125849627 \times 10^{-7}$	$4.8573132442 \times 10^{-7}$
B(7)................	$-2.9032251684 \times 10^{-9}$	$-5.2094815173 \times 10^{-9}$	$-3.8382718939 \times 10^{-9}$	$-6.1445282582 \times 10^{-9}$	$-2.3898974345 \times 10^{-9}$	$-4.6961538119 \times 10^{-9}$
B(8)................	$1.9881512159 \times 10^{-11}$	$3.6920742674 \times 10^{-11}$	$2.7684122233 \times 10^{-11}$	$4.4723352843 \times 10^{-11}$	$1.5931957622 \times 10^{-11}$	$3.2971188358 \times 10^{-11}$
B(9)................	$-9.9174829612 \times 10^{-14}$	$-1.9020522841 \times 10^{-13}$	$-1.4483161512 \times 10^{-13}$	$-2.3586201427 \times 10^{-13}$	$-7.7417132540 \times 10^{-14}$	$-1.6844753253 \times 10^{-13}$
B(10)...............	$3.5645229362 \times 10^{-16}$	$7.0508285353 \times 10^{-16}$	$5.4390389051 \times 10^{-16}$	$8.9253445111 \times 10^{-16}$	$2.7100280116 \times 10^{-16}$	$6.1963336555 \times 10^{-16}$
B(11)...............	$-8.9864698504 \times 10^{-19}$	$-1.8317974022 \times 10^{-18}$	$-1.4282076268 \times 10^{-18}$	$-2.3613580435 \times 10^{-18}$	$-6.6485927163 \times 10^{-19}$	$-1.5980097000 \times 10^{-18}$
B(12)...............	$1.5071673023 \times 10^{-21}$	$3.1644035401 \times 10^{-21}$	$2.4882871621 \times 10^{-21}$	$4.1455233949 \times 10^{-21}$	$1.0835762248 \times 10^{-21}$	$2.7408124807 \times 10^{-21}$
B(13)...............	$-1.5093916059 \times 10^{-24}$	$-3.2636069898 \times 10^{-24}$	$-2.5831198571 \times 10^{-24}$	$-4.3373352305 \times 10^{-24}$	$-1.0525122333 \times 10^{-24}$	$-2.8067276336 \times 10^{-24}$
B(14)...............	$6.8264293980 \times 10^{-28}$	$1.5201593461 \times 10^{-27}$	$1.2089129004 \times 10^{-27}$	$2.0464292991 \times 10^{-27}$	$4.6057748723 \times 10^{-28}$	$1.2980938998 \times 10^{-27}$

TABLE 5. *Thermocouple KP versus* Au-0.07 *at%* Fe_{11} —*thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	962.74	17.139	43.4	120	2065.91	19.513	31.8
1	7.85	8.673	1565.8	61	979.90	17.183	43.6	121	2085.44	19.545	31.5
2	17.27	10.127	1346.7	62	997.11	17.226	43.7	122	2105.00	19.576	31.2
3	28.04	11.375	1152.4	63	1014.36	17.270	43.7	123	2124.59	19.607	30.9
4	39.96	12.439	980.4	64	1031.65	17.314	43.7	124	2144.21	19.638	30.6
5	52.86	13.342	828.8	65	1048.99	17.358	43.7	125	2163.87	19.668	30.3
6	66.59	14.103	695.4	66	1066.36	17.401	43.7	126	2183.55	19.698	30.0
7	81.03	14.739	578.6	67	1083.79	17.445	43.6	127	2203.26	19.728	29.7
8	96.04	15.265	476.7	68	1101.25	17.489	43.5	128	2223.00	19.758	29.4
9	111.52	15.697	388.1	69	1118.76	17.532	43.4	129	2242.78	19.787	29.2
10	127.40	16.045	311.5	70	1136.32	17.575	43.3	130	2262.58	19.816	28.9
11	143.59	16.323	245.6	71	1153.92	17.619	43.2	131	2282.41	19.845	28.7
12	160.03	16.540	189.2	72	1171.56	17.662	43.1	132	2302.27	19.873	28.4
13	176.65	16.704	141.4	73	1189.24	17.705	42.9	133	2322.16	19.902	28.2
14	193.42	16.825	101.0	74	1206.96	17.748	42.8	134	2342.07	19.930	28.0
15	210.29	16.909	67.3	75	1224.73	17.790	42.7	135	2362.02	19.958	27.7
16	227.23	16.962	39.5	76	1242.55	17.833	42.6	136	2381.99	19.985	27.5
17	244.21	16.989	16.8	77	1260.40	17.875	42.4	137	2401.99	20.013	27.3
18	261.20	16.997	-1.4	78	1278.30	17.918	42.3	138	2422.01	20.040	27.1
19	278.19	16.988	-15.7	79	1296.24	17.960	42.2	139	2442.07	20.067	26.9
20	295.17	16.966	-26.6	80	1314.22	18.002	42.0	140	2462.15	20.094	26.7
21	312.12	16.935	-34.6	81	1332.24	18.044	41.9	141	2482.25	20.120	26.5
22	329.04	16.898	-40.1	82	1350.30	18.086	41.8	142	2502.39	20.147	26.3
23	345.92	16.856	-43.5	83	1368.41	18.128	41.6	143	2522.55	20.173	26.1
24	362.75	16.811	-45.1	84	1386.56	18.169	41.5	144	2542.73	20.199	26.0
25	379.54	16.766	-45.3	85	1404.75	18.211	41.3	145	2562.94	20.225	25.8
26	396.28	16.721	-44.2	86	1422.98	18.252	41.2	146	2583.18	20.250	25.6
27	412.98	16.678	-42.1	87	1441.25	18.293	41.0	147	2603.45	20.276	25.4
28	429.64	16.637	-39.2	88	1459.57	18.334	40.9	148	2623.73	20.301	25.3
29	446.26	16.600	-35.7	89	1477.92	18.375	40.7	149	2644.05	20.327	25.1
30	462.84	16.566	-31.8	90	1496.32	18.415	40.5	150	2664.39	20.352	24.9
31	479.39	16.536	-27.5	91	1514.75	18.456	40.3	151	2684.75	20.376	24.7
32	495.92	16.511	-23.0	92	1533.23	18.496	40.2	152	2705.14	20.401	24.6
33	512.42	16.490	-18.4	93	1551.74	18.536	40.0	153	2725.55	20.426	24.4
34	528.90	16.474	-13.8	94	1570.30	18.576	39.7	154	2745.99	20.450	24.2
35	545.37	16.463	-9.2	95	1588.89	18.615	39.5	155	2766.45	20.474	24.1
36	561.83	16.456	-4.7	96	1607.53	18.655	39.3	156	2786.94	20.498	23.9
37	578.28	16.453	-0.4	97	1626.20	18.694	39.1	157	2807.45	20.522	23.7
38	594.73	16.455	3.8	98	1644.92	18.733	38.8	158	2827.98	20.545	23.5
39	611.19	16.461	7.8	99	1663.67	18.772	38.5	159	2848.54	20.569	23.4
40	627.66	16.471	11.6	100	1682.46	18.810	38.3	160	2869.12	20.592	23.2
41	644.13	16.484	15.2	101	1701.29	18.848	38.0	161	2889.72	20.615	23.0
42	660.63	16.501	18.5	102	1720.16	18.886	37.7	162	2910.35	20.638	22.8
43	677.14	16.521	21.5	103	1739.06	18.924	37.4	163	2931.00	20.661	22.6
44	693.67	16.544	24.3	104	1758.00	18.961	37.1	164	2951.67	20.683	22.5
45	710.22	16.569	26.9	105	1776.98	18.998	36.8	165	2972.37	20.706	22.3
46	726.81	16.597	29.3	106	1796.00	19.035	36.5	166	2993.08	20.728	22.1
47	743.42	16.628	31.4	107	1815.05	19.071	36.2	167	3013.82	20.750	21.9
48	760.06	16.660	33.3	108	1834.14	19.107	35.8	168	3034.58	20.772	21.7
49	776.74	16.694	35.0	109	1853.27	19.143	35.5	169	3055.37	20.793	21.5
50	793.45	16.730	36.5	110	1872.43	19.178	35.2	170	3076.17	20.815	21.3
51	810.20	16.767	37.8	111	1891.62	19.213	34.8	171	3096.99	20.836	21.1
52	826.99	16.806	38.9	112	1910.85	19.248	34.5	172	3117.84	20.857	21.0
53	843.81	16.845	39.9	113	1930.12	19.282	34.2	173	3138.71	20.878	20.8
54	860.68	16.885	40.7	114	1949.42	19.316	33.8	174	3159.60	20.899	20.6
55	877.58	16.926	41.4	115	1968.75	19.350	33.5	175	3180.51	20.919	20.4
56	894.53	16.968	42.0	116	1988.12	19.383	33.2	176	3201.44	20.939	20.2
57	911.52	17.010	42.5	117	2007.52	19.416	32.8	177	3222.38	20.960	20.1
58	928.55	17.053	42.9	118	2026.95	19.449	32.5	178	3243.35	20.980	19.9
59	945.63	17.096	43.2	119	2046.41	19.481	32.2	179	3264.34	20.999	19.7
60	962.74	17.139	43.4	120	2065.91	19.513	31.8	180	3285.35	21.019	19.6

TABLE 5. *Thermocouple KP versus* Au-0.07 *at%* Fe_{11} – *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) – Continued

T K	E μV	S μV/K	dS/dT nV/K²
180	3285.35	21.019	19.6
181	3306.38	21.038	19.4
182	3327.43	21.058	19.2
183	3348.50	21.077	19.1
184	3369.58	21.096	18.9
185	3390.69	21.115	18.8
186	3411.81	21.133	18.6
187	3432.96	21.152	18.5
188	3454.12	21.171	18.4
189	3475.30	21.189	18.3
190	3496.49	21.207	18.1
191	3517.71	21.225	18.0
192	3538.94	21.243	17.9
193	3560.20	21.261	17.8
194	3581.47	21.279	17.7
195	3602.75	21.296	17.6
196	3624.06	21.314	17.5
197	3645.38	21.331	17.4
198	3666.72	21.348	17.3
199	3688.08	21.366	17.2
200	3709.45	21.383	17.1
201	3730.84	21.400	17.0
202	3752.25	21.417	16.9
203	3773.68	21.434	16.8
204	3795.12	21.450	16.7
205	3816.58	21.467	16.5
206	3838.05	21.483	16.4
207	3859.54	21.500	16.3
208	3881.05	21.516	16.2
209	3902.58	21.532	16.0
210	3924.12	21.548	15.9
211	3945.67	21.564	15.8
212	3967.24	21.580	15.6
213	3988.83	21.595	15.4
214	4010.43	21.610	15.3
215	4032.05	21.626	15.1
216	4053.69	21.641	14.9
217	4075.33	21.655	14.7
218	4097.00	21.670	14.5
219	4118.67	21.684	14.3
220	4140.36	21.698	14.0
221	4162.07	21.712	13.8
222	4183.79	21.726	13.6
223	4205.52	21.739	13.3
224	4227.27	21.753	13.1
225	4249.03	21.766	12.8
226	4270.80	21.778	12.5
227	4292.58	21.791	12.3
228	4314.38	21.803	12.0
229	4336.19	21.815	11.8
230	4358.01	21.826	11.5
231	4379.84	21.838	11.3
232	4401.68	21.849	11.0
233	4423.54	21.860	10.8
234	4445.40	21.870	10.5
235	4467.28	21.881	10.3
236	4489.17	21.891	10.1
237	4511.06	21.901	9.9
238	4532.97	21.911	9.8
239	4554.88	21.921	9.6
240	4576.81	21.930	9.5
240	4576.81	21.930	9.5
241	4598.74	21.940	9.4
242	4620.69	21.949	9.3
243	4642.64	21.958	9.3
244	4664.61	21.968	9.2
245	4686.58	21.977	9.2
246	4708.56	21.986	9.3
247	4730.55	21.995	9.3
248	4752.55	22.005	9.4
249	4774.56	22.014	9.5
250	4796.58	22.024	9.6
251	4818.61	22.034	9.8
252	4840.64	22.043	10.0
253	4862.69	22.053	10.2
254	4884.75	22.064	10.3
255	4906.82	22.074	10.6
256	4928.90	22.085	10.8
257	4950.99	22.096	11.0
258	4973.09	22.107	11.1
259	4995.20	22.118	11.3
260	5017.33	22.129	11.5
261	5039.46	22.141	11.6
262	5061.61	22.152	11.6
263	5083.77	22.164	11.7
264	5105.94	22.176	11.6
265	5128.12	22.187	11.5
266	5150.31	22.199	11.3
267	5172.52	22.210	11.1
268	5194.73	22.221	10.7
269	5216.96	22.231	10.3
270	5239.19	22.241	9.7
271	5261.44	22.251	9.0
272	5283.70	22.259	8.2
273	5305.96	22.267	7.3
274	5328.23	22.274	6.3
275	5350.51	22.280	5.2
276	5372.79	22.284	4.0
277	5395.08	22.288	2.7
278	5417.36	22.290	1.3
279	5439.65	22.290	-0.1
280	5461.94	22.289	-1.4

TABLE 6. *Thermocouple KP versus* Au-0.02 *at%* Fe45*—thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	808.49	13.053	55.5	120	1694.43	16.360	45.9
1	8.28	9.226	1787.8	61	821.57	13.109	56.1	121	1710.81	16.406	45.6
2	18.34	10.856	1479.4	62	834.71	13.166	56.6	122	1727.24	16.452	45.2
3	29.89	12.198	1209.2	63	847.90	13.222	57.1	123	1743.72	16.497	44.9
4	42.65	13.286	973.4	64	861.15	13.280	57.5	124	1760.24	16.541	44.6
5	56.39	14.155	768.6	65	874.46	13.337	57.8	125	1776.80	16.586	44.2
6	70.90	14.833	591.6	66	887.83	13.395	58.0	126	1793.41	16.630	43.9
7	86.00	15.346	439.4	67	901.25	13.453	58.2	127	1810.06	16.674	43.6
8	101.55	15.719	309.3	68	914.73	13.512	58.4	128	1826.75	16.717	43.4
9	117.40	15.972	199.1	69	928.27	13.570	58.5	129	1843.49	16.760	43.1
10	133.46	16.123	106.3	70	941.87	13.629	58.6	130	1860.27	16.803	42.8
11	149.62	16.189	29.1	71	955.53	13.687	58.6	131	1877.10	16.846	42.6
12	165.81	16.186	-34.4	72	969.25	13.746	58.7	132	1893.97	16.888	42.4
13	181.97	16.125	-85.9	73	983.02	13.805	58.7	133	1910.88	16.931	42.1
14	198.04	16.017	-126.9	74	996.86	13.863	58.8	134	1927.83	16.973	41.9
15	213.99	15.874	-158.7	75	1010.75	13.922	58.8	135	1944.82	17.015	41.7
16	229.78	15.703	-182.5	76	1024.70	13.981	58.8	136	1961.86	17.056	41.5
17	245.39	15.511	-199.5	77	1038.71	14.040	58.7	137	1978.93	17.098	41.3
18	260.80	15.306	-210.6	78	1052.78	14.098	58.7	138	1996.05	17.139	41.1
19	276.00	15.091	-216.7	79	1066.91	14.157	58.7	139	2013.21	17.180	40.9
20	290.98	14.874	-218.6	80	1081.09	14.216	58.6	140	2030.41	17.221	40.8
21	305.75	14.656	-216.9	81	1095.34	14.274	58.6	141	2047.65	17.261	40.6
22	320.29	14.441	-212.4	82	1109.64	14.333	58.5	142	2064.93	17.302	40.4
23	334.63	14.231	-205.5	83	1124.00	14.391	58.4	143	2082.26	17.342	40.2
24	348.76	14.030	-196.7	84	1138.42	14.450	58.3	144	2099.62	17.382	40.0
25	362.69	13.839	-186.5	85	1152.90	14.508	58.2	145	2117.02	17.422	39.9
26	376.44	13.658	-175.2	86	1167.44	14.566	58.1	146	2134.46	17.462	39.7
27	390.01	13.488	-163.1	87	1182.04	14.624	57.9	147	2151.94	17.502	39.5
28	403.42	13.332	-150.5	88	1196.69	14.682	57.8	148	2169.47	17.541	39.3
29	416.68	13.188	-137.6	89	1211.40	14.740	57.6	149	2187.03	17.580	39.1
30	429.80	13.057	-124.6	90	1226.17	14.797	57.4	150	2204.63	17.619	38.9
31	442.80	12.938	-111.7	91	1240.99	14.854	57.2	151	2222.26	17.658	38.7
32	455.68	12.833	-99.0	92	1255.88	14.911	56.9	152	2239.94	17.696	38.5
33	468.47	12.740	-86.7	93	1270.82	14.968	56.7	153	2257.66	17.735	38.2
34	481.17	12.659	-74.8	94	1285.81	15.025	56.4	154	2275.41	17.773	38.0
35	493.79	12.590	-63.4	95	1300.87	15.081	56.1	155	2293.20	17.811	37.8
36	506.35	12.533	-52.5	96	1315.97	15.137	55.8	156	2311.03	17.848	37.5
37	518.86	12.485	-42.2	97	1331.14	15.193	55.5	157	2328.90	17.886	37.3
38	531.33	12.448	-32.5	98	1346.36	15.248	55.1	158	2346.80	17.923	37.0
39	543.76	12.420	-23.4	99	1361.63	15.303	54.8	159	2364.75	17.960	36.7
40	556.17	12.401	-15.0	100	1376.97	15.357	54.4	160	2382.72	17.996	36.5
41	568.56	12.390	-7.1	101	1392.35	15.412	54.0	161	2400.74	18.033	36.2
42	580.95	12.386	0.1	102	1407.79	15.465	53.6	162	2418.79	18.069	35.9
43	593.34	12.390	6.7	103	1423.28	15.519	53.2	163	2436.88	18.105	35.6
44	605.73	12.400	12.8	104	1438.83	15.572	52.8	164	2455.00	18.140	35.3
45	618.14	12.415	18.3	105	1454.42	15.624	52.3	165	2473.16	18.175	35.0
46	630.56	12.436	23.4	106	1470.07	15.676	51.9	166	2491.35	18.210	34.7
47	643.01	12.462	27.9	107	1485.78	15.728	51.5	167	2509.58	18.245	34.4
48	655.49	12.492	31.9	108	1501.53	15.779	51.0	168	2527.84	18.279	34.1
49	668.00	12.526	35.6	109	1517.34	15.830	50.6	169	2546.13	18.313	33.8
50	680.54	12.563	38.8	110	1533.19	15.881	50.1	170	2564.46	18.346	33.5
51	693.12	12.603	41.7	111	1549.10	15.930	49.7	171	2582.83	18.380	33.2
52	705.75	12.646	44.2	112	1565.05	15.980	49.2	172	2601.22	18.413	32.9
53	718.42	12.691	46.4	113	1581.06	16.029	48.8	173	2619.65	18.445	32.6
54	731.13	12.739	48.3	114	1597.11	16.078	48.4	174	2638.11	18.478	32.3
55	743.90	12.788	50.0	115	1613.21	16.126	47.9	175	2656.61	18.510	32.0
56	756.71	12.839	51.5	116	1629.36	16.173	47.5	176	2675.13	18.542	31.7
57	769.57	12.891	52.7	117	1645.56	16.221	47.1	177	2693.69	18.573	31.4
58	782.49	12.944	53.8	118	1661.80	16.268	46.7	178	2712.28	18.605	31.1
59	795.46	12.998	54.7	119	1678.09	16.314	46.3	179	2730.90	18.636	30.8
60	808.49	13.053	55.5	120	1694.43	16.360	45.9	180	2749.55	18.666	30.6

TABLE 6. *Thermocouple KP versus* Au-0.02 *at%* Fe_{45} — *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) — Continued

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
180	2749.55	18.666	30.6	240	3918.02	20.167	19.1				
181	2768.23	18.697	30.3	241	3938.19	20.186	19.0				
182	2786.94	18.727	30.1	242	3958.39	20.205	19.0				
183	2805.69	18.757	29.9	243	3978.60	20.224	19.0				
184	2824.46	18.787	29.6	244	3998.84	20.243	19.0				
185	2843.26	18.816	29.4	245	4019.09	20.262	18.9				
186	2862.09	18.845	29.2	246	4039.36	20.281	19.0				
187	2880.95	18.875	29.0	247	4059.65	20.299	19.0				
188	2899.84	18.903	28.8	248	4079.96	20.318	19.0				
189	2918.76	18.932	28.6	249	4100.29	20.337	18.9				
190	2937.70	18.961	28.5	250	4120.63	20.356	18.9				
191	2956.68	18.989	28.3	251	4141.00	20.375	18.9				
192	2975.68	19.017	28.2	252	4161.38	20.394	18.8				
193	2994.71	19.046	28.0	253	4181.79	20.413	18.7				
194	3013.77	19.073	27.9	254	4202.21	20.431	18.5				
195	3032.86	19.101	27.7	255	4222.65	20.450	18.3				
196	3051.98	19.129	27.6	256	4243.11	20.468	18.1				
197	3071.12	19.156	27.5	257	4263.59	20.486	17.7				
198	3090.29	19.184	27.4	258	4284.08	20.503	17.4				
199	3109.49	19.211	27.2	259	4304.59	20.521	16.9				
200	3128.71	19.238	27.1	260	4325.12	20.537	16.4				
201	3147.96	19.265	27.0	261	4345.67	20.553	15.9				
202	3167.24	19.292	26.9	262	4366.23	20.569	15.2				
203	3186.55	19.319	26.7	263	4386.80	20.584	14.6				
204	3205.88	19.346	26.6	264	4407.40	20.598	13.9				
205	3225.24	19.372	26.5	265	4428.00	20.612	13.2				
206	3244.62	19.399	26.3	266	4448.62	20.625	12.6				
207	3264.04	19.425	26.2	267	4469.25	20.637	12.0				
208	3283.47	19.451	26.0	268	4489.89	20.649	11.5				
209	3302.94	19.477	25.9	269	4510.55	20.660	11.2				
210	3322.43	19.503	25.7	270	4531.21	20.671	11.1				
211	3341.94	19.529	25.5	271	4551.89	20.682	11.4				
212	3361.49	19.554	25.3	272	4572.58	20.694	12.0				
213	3381.05	19.579	25.1	273	4593.28	20.706	13.2				
214	3400.64	19.604	24.9	274	4613.99	20.721	15.1				
215	3420.26	19.629	24.7	275	4634.72	20.737	17.8				
216	3439.90	19.653	24.4	276	4655.47	20.757	21.5				
217	3459.57	19.678	24.2	277	4676.23	20.780	26.5				
218	3479.26	19.702	23.9	278	4697.03	20.810	33.0				
219	3498.97	19.726	23.7	279	4717.86	20.847	41.2				
220	3518.71	19.749	23.4	280	4738.72	20.893	51.5				
221	3538.47	19.772	23.1								
222	3558.25	19.795	22.9								
223	3578.06	19.818	22.6								
224	3597.89	19.841	22.3								
225	3617.74	19.863	22.0								
226	3637.62	19.885	21.7								
227	3657.51	19.906	21.5								
228	3677.43	19.928	21.2								
229	3697.37	19.949	20.9								
230	3717.32	19.969	20.7								
231	3737.30	19.990	20.4								
232	3757.30	20.010	20.2								
233	3777.32	20.030	20.0								
234	3797.37	20.050	19.8								
235	3817.43	20.070	19.6								
236	3837.51	20.090	19.5								
237	3857.60	20.109	19.4								
238	3877.72	20.128	19.2								
239	3897.86	20.148	19.2								
240	3918.02	20.167	19.1								

TABLE 7. *Thermocouple copper versus* Au-0.07 *at%* Fe_{11} — *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	719.52	9.331	-81.7	120	1162.03	5.835	-41.8
1	7.78	8.531	1423.5	61	728.81	9.250	-80.9	121	1167.85	5.793	-41.4
2	16.98	9.839	1197.0	62	738.02	9.169	-80.1	122	1173.62	5.752	-41.1
3	27.38	10.934	997.5	63	747.15	9.089	-79.3	123	1179.35	5.711	-40.7
4	38.79	11.842	822.3	64	756.20	9.010	-78.5	124	1185.04	5.671	-40.3
5	51.01	12.586	669.0	65	765.17	8.932	-77.7	125	1190.69	5.630	-40.0
6	63.91	13.187	535.4	66	774.07	8.855	-76.9	126	1196.30	5.591	-39.6
7	77.35	13.663	419.3	67	782.88	8.778	-76.1	127	1201.87	5.551	-39.2
8	91.20	14.030	318.9	68	791.62	8.703	-75.2	128	1207.41	5.512	-38.8
9	105.38	14.305	232.5	69	800.29	8.628	-74.4	129	1212.90	5.474	-38.5
10	119.78	14.500	158.5	70	808.88	8.554	-73.5	130	1218.35	5.435	-38.1
11	134.35	14.626	95.5	71	817.40	8.481	-72.6	131	1223.77	5.397	-37.7
12	149.02	14.694	42.3	72	825.84	8.409	-71.7	132	1229.15	5.360	-37.3
13	163.72	14.713	-2.4	73	834.22	8.338	-70.7	133	1234.49	5.323	-36.9
14	178.43	14.692	-39.5	74	842.52	8.267	-69.8	134	1239.79	5.286	-36.5
15	193.10	14.636	-70.0	75	850.75	8.198	-68.9	135	1245.06	5.250	-36.1
16	207.69	14.553	-94.8	76	858.92	8.130	-67.9	136	1250.29	5.214	-35.7
17	222.20	14.448	-114.7	77	867.01	8.062	-67.0	137	1255.49	5.178	-35.3
18	236.58	14.326	-130.2	78	875.04	7.996	-66.0	138	1260.65	5.143	-34.9
19	250.84	14.189	-142.1	79	883.00	7.930	-65.1	139	1265.78	5.109	-34.6
20	264.96	14.042	-150.8	80	890.90	7.866	-64.2	140	1270.87	5.074	-34.2
21	278.92	13.888	-156.9	81	898.73	7.802	-63.3	141	1275.92	5.040	-33.8
22	292.73	13.729	-160.8	82	906.51	7.739	-62.3	142	1280.95	5.007	-33.4
23	306.38	13.567	-162.8	83	914.21	7.677	-61.4	143	1285.94	4.973	-33.1
24	319.87	13.404	-163.2	84	921.86	7.616	-60.6	144	1290.89	4.940	-32.7
25	333.19	13.241	-162.4	85	929.45	7.556	-59.7	145	1295.82	4.908	-32.4
26	346.35	13.080	-160.7	86	936.97	7.497	-58.9	146	1300.71	4.876	-32.0
27	359.35	12.920	-158.1	87	944.44	7.438	-58.0	147	1305.57	4.844	-31.7
28	372.19	12.764	-155.0	88	951.85	7.381	-57.2	148	1310.40	4.812	-31.4
29	384.88	12.610	-151.5	89	959.20	7.324	-56.5	149	1315.20	4.781	-31.1
30	397.41	12.461	-147.6	90	966.50	7.268	-55.7	150	1319.96	4.750	-30.8
31	409.80	12.315	-143.6	91	973.74	7.212	-55.0	151	1324.70	4.720	-30.5
32	422.04	12.173	-139.5	92	980.92	7.158	-54.3	152	1329.40	4.689	-30.2
33	434.15	12.036	-135.4	93	988.05	7.104	-53.6	153	1334.07	4.659	-29.9
34	446.12	11.903	-131.4	94	995.13	7.051	-52.9	154	1338.72	4.629	-29.7
35	457.96	11.773	-127.4	95	1002.15	6.998	-52.3	155	1343.33	4.600	-29.4
36	469.67	11.648	-123.6	96	1009.13	6.946	-51.7	156	1347.92	4.571	-29.2
37	481.25	11.526	-120.0	97	1016.05	6.894	-51.1	157	1352.47	4.542	-28.9
38	492.72	11.408	-116.6	98	1022.92	6.844	-50.6	158	1357.00	4.513	-28.7
39	504.07	11.293	-113.4	99	1029.73	6.793	-50.0	159	1361.50	4.484	-28.5
40	515.31	11.181	-110.3	100	1036.50	6.744	-49.5	160	1365.97	4.456	-28.3
41	526.43	11.072	-107.6	101	1043.22	6.694	-49.0	161	1370.41	4.427	-28.1
42	537.45	10.966	-105.0	102	1049.89	6.645	-48.6	162	1374.82	4.399	-27.9
43	548.36	10.862	-102.6	103	1056.51	6.597	-48.1	163	1379.21	4.372	-27.8
44	559.17	10.760	-100.4	104	1063.09	6.549	-47.7	164	1383.57	4.344	-27.6
45	569.89	10.661	-98.4	105	1069.61	6.502	-47.3	165	1387.90	4.316	-27.4
46	580.50	10.564	-96.6	106	1076.09	6.455	-46.8	166	1392.20	4.289	-27.2
47	591.01	10.468	-94.9	107	1082.52	6.408	-46.5	167	1396.48	4.262	-27.1
48	601.43	10.374	-93.4	108	1088.90	6.362	-46.1	168	1400.72	4.235	-26.9
49	611.76	10.281	-92.0	109	1095.24	6.316	-45.7	169	1404.95	4.208	-26.8
50	622.00	10.190	-90.8	110	1101.54	6.270	-45.3	170	1409.14	4.181	-26.6
51	632.14	10.099	-89.6	111	1107.78	6.225	-45.0	171	1413.31	4.155	-26.5
52	642.20	10.010	-88.5	112	1113.99	6.180	-44.6	172	1417.45	4.128	-26.3
53	652.16	9.922	-87.5	113	1120.15	6.136	-44.2	173	1421.57	4.102	-26.2
54	662.04	9.835	-86.6	114	1126.26	6.092	-43.9	174	1425.66	4.076	-26.0
55	671.83	9.749	-85.7	115	1132.33	6.048	-43.5	175	1429.72	4.050	-25.8
56	681.54	9.664	-84.8	116	1138.36	6.005	-43.2	176	1433.76	4.025	-25.7
57	691.16	9.579	-84.0	117	1144.34	5.962	-42.9	177	1437.77	3.999	-25.5
58	700.70	9.496	-83.2	118	1150.28	5.919	-42.5	178	1441.75	3.974	-25.3
59	710.15	9.413	-82.5	119	1156.18	5.877	-42.2	179	1445.71	3.948	-25.1
60	719.52	9.331	-81.7	120	1162.03	5.835	-41.8	180	1449.65	3.923	-24.9

TABLE 7. *Thermocouple copper versus* Au-0.07 *at%* Fe_{11} *— thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) — Continued

T K	E μV	S μV/K	dS/dT nV/K²
180	1449.65	3.923	-24.9
181	1453.56	3.898	-24.7
182	1457.45	3.874	-24.5
183	1461.31	3.849	-24.3
184	1465.15	3.825	-24.1
185	1468.96	3.801	-23.9
186	1472.75	3.777	-23.6
187	1476.51	3.754	-23.4
188	1480.26	3.731	-23.2
189	1483.98	3.708	-22.9
190	1487.67	3.685	-22.7
191	1491.35	3.662	-22.4
192	1495.00	3.640	-22.1
193	1498.63	3.618	-21.9
194	1502.23	3.596	-21.6
195	1505.82	3.575	-21.3
196	1509.38	3.554	-21.1
197	1512.93	3.533	-20.8
198	1516.45	3.512	-20.5
199	1519.95	3.492	-20.3
200	1523.43	3.472	-20.0
201	1526.89	3.452	-19.7
202	1530.33	3.432	-19.5
203	1533.76	3.413	-19.3
204	1537.16	3.394	-19.0
205	1540.54	3.375	-18.8
206	1543.91	3.356	-18.6
207	1547.26	3.337	-18.4
208	1550.58	3.319	-18.3
209	1553.89	3.301	-18.1
210	1557.19	3.283	-18.0
211	1560.46	3.265	-17.8
212	1563.72	3.247	-17.7
213	1566.95	3.229	-17.6
214	1570.17	3.212	-17.6
215	1573.38	3.194	-17.5
216	1576.56	3.177	-17.5
217	1579.73	3.159	-17.4
218	1582.88	3.142	-17.4
219	1586.01	3.125	-17.4
220	1589.13	3.107	-17.5
221	1592.23	3.090	-17.5
222	1595.31	3.072	-17.5
223	1598.37	3.055	-17.6
224	1601.42	3.037	-17.6
225	1604.45	3.019	-17.7
226	1607.46	3.002	-17.7
227	1610.45	2.984	-17.8
228	1613.42	2.966	-17.9
229	1616.38	2.948	-17.9
230	1619.32	2.930	-18.0
231	1622.24	2.912	-18.0
232	1625.15	2.894	-18.0
233	1628.03	2.876	-18.0
234	1630.90	2.858	-18.0
235	1633.75	2.840	-17.9
236	1636.58	2.822	-17.9
237	1639.39	2.805	-17.8
238	1642.19	2.787	-17.7
239	1644.97	2.769	-17.5
240	1647.73	2.752	-17.3

T K	E μV	S μV/K	dS/dT nV/K²
240	1647.73	2.752	-17.3
241	1650.47	2.735	-17.1
242	1653.20	2.718	-16.9
243	1655.90	2.701	-16.6
244	1658.60	2.684	-16.3
245	1661.27	2.668	-16.0
246	1663.93	2.653	-15.6
247	1666.58	2.637	-15.2
248	1669.21	2.622	-14.8
249	1671.82	2.607	-14.4
250	1674.42	2.593	-14.0
251	1677.01	2.579	-13.6
252	1679.58	2.566	-13.1
253	1682.14	2.553	-12.7
254	1684.69	2.541	-12.3
255	1687.22	2.528	-12.0
256	1689.75	2.517	-11.6
257	1692.26	2.505	-11.3
258	1694.76	2.494	-11.0
259	1697.25	2.483	-10.8
260	1699.72	2.472	-10.7
261	1702.19	2.462	-10.6
262	1704.65	2.451	-10.5
263	1707.09	2.441	-10.5
264	1709.53	2.430	-10.6
265	1711.95	2.419	-10.8
266	1714.37	2.409	-10.9
267	1716.77	2.398	-11.1
268	1719.16	2.386	-11.3
269	1721.54	2.375	-11.5
270	1723.91	2.363	-11.6
271	1726.27	2.352	-11.6
272	1728.62	2.340	-11.5
273	1730.95	2.329	-11.1
274	1733.27	2.318	-10.4
275	1735.59	2.308	-9.3
276	1737.89	2.300	-7.6
277	1740.19	2.293	-5.2
278	1742.48	2.290	-2.1
279	1744.77	2.289	2.1
280	1747.06	2.294	7.6

T K	E μV	S μV/K	dS/dT nV/K²

TABLE 8. *Thermocouple copper versus* Au-0.02 *at%* Fe_{45} — *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	565.27	5.245	-69.6	120	790.55	2.682	-27.7
1	8.20	9.084	1645.5	61	570.48	5.176	-68.4	121	793.22	2.655	-27.4
2	18.06	10.568	1329.6	62	575.62	5.108	-67.1	122	795.86	2.628	-27.0
3	29.24	11.757	1054.3	63	580.70	5.042	-66.0	123	798.48	2.601	-26.7
4	41.48	12.689	815.3	64	585.70	4.976	-64.8	124	801.07	2.574	-26.4
5	54.55	13.399	608.9	65	590.65	4.912	-63.7	125	803.63	2.548	-26.0
6	68.22	13.916	431.5	66	595.53	4.849	-62.6	126	806.16	2.522	-25.7
7	82.32	14.270	280.0	67	600.35	4.787	-61.5	127	808.67	2.497	-25.3
8	96.71	14.484	151.5	68	605.10	4.726	-60.4	128	811.15	2.471	-24.9
9	111.25	14.580	43.4	69	609.80	4.666	-59.3	129	813.61	2.447	-24.5
10	125.84	14.577	-46.7	70	614.43	4.607	-58.2	130	816.05	2.422	-24.1
11	140.38	14.492	-121.0	71	619.01	4.550	-57.1	131	818.46	2.398	-23.7
12	154.80	14.340	-181.4	72	623.53	4.493	-56.0	132	820.85	2.375	-23.3
13	169.04	14.133	-229.7	73	628.00	4.438	-54.9	133	823.21	2.352	-22.9
14	183.05	13.884	-267.4	74	632.41	4.383	-53.9	134	825.55	2.329	-22.5
15	196.80	13.601	-296.0	75	636.77	4.330	-52.8	135	827.87	2.307	-22.1
16	210.25	13.294	-316.8	76	641.07	4.278	-51.7	136	830.16	2.285	-21.7
17	223.38	12.970	-331.0	77	645.32	4.226	-50.7	137	832.44	2.263	-21.3
18	236.18	12.634	-339.4	78	649.52	4.176	-49.6	138	834.69	2.242	-20.9
19	248.65	12.293	-343.1	79	653.67	4.127	-48.6	139	836.92	2.222	-20.5
20	260.77	11.950	-342.8	80	657.78	4.079	-47.6	140	839.13	2.201	-20.1
21	272.55	11.608	-339.2	81	661.83	4.032	-46.6	141	841.32	2.181	-19.7
22	283.99	11.272	-333.0	82	665.84	3.986	-45.6	142	843.50	2.162	-19.3
23	295.09	10.943	-324.7	83	669.81	3.941	-44.6	143	845.65	2.143	-19.0
24	305.88	10.623	-314.8	84	673.72	3.897	-43.7	144	847.78	2.124	-18.6
25	316.34	10.314	-303.7	85	677.60	3.853	-42.8	145	849.90	2.105	-18.3
26	326.51	10.016	-291.7	86	681.43	3.811	-42.0	146	851.99	2.087	-18.0
27	336.38	9.731	-279.1	87	685.22	3.769	-41.1	147	854.07	2.069	-17.6
28	345.97	9.458	-266.3	88	688.97	3.729	-40.3	148	856.13	2.052	-17.3
29	355.30	9.198	-253.3	89	692.68	3.689	-39.6	149	858.17	2.035	-17.1
30	364.37	8.951	-240.4	90	696.35	3.650	-38.9	150	860.20	2.018	-16.8
31	373.21	8.717	-227.8	91	699.98	3.611	-38.2	151	862.21	2.001	-16.5
32	381.81	8.495	-215.5	92	703.57	3.573	-37.5	152	864.20	1.985	-16.3
33	390.20	8.286	-203.7	93	707.13	3.536	-36.9	153	866.18	1.969	-16.1
34	398.39	8.088	-192.3	94	710.64	3.499	-36.3	154	868.14	1.953	-15.9
35	406.38	7.901	-181.6	95	714.12	3.463	-35.7	155	870.08	1.937	-15.7
36	414.19	7.725	-171.4	96	717.57	3.428	-35.2	156	872.01	1.921	-15.5
37	421.83	7.558	-161.8	97	720.98	3.393	-34.7	157	873.93	1.906	-15.4
38	429.31	7.401	-152.9	98	724.36	3.359	-34.3	158	875.82	1.890	-15.3
39	436.64	7.252	-144.6	99	727.70	3.324	-33.8	159	877.71	1.875	-15.1
40	443.82	7.111	-136.9	100	731.01	3.291	-33.4	160	879.57	1.860	-15.0
41	450.86	6.978	-129.8	101	734.28	3.258	-33.0	161	881.43	1.845	-14.9
42	457.78	6.851	-123.3	102	737.52	3.225	-32.7	162	883.26	1.830	-14.9
43	464.57	6.731	-117.4	103	740.73	3.192	-32.4	163	885.09	1.815	-14.8
44	471.24	6.616	-111.9	104	743.91	3.160	-32.0	164	886.90	1.801	-14.7
45	477.80	6.507	-107.0	105	747.05	3.128	-31.7	165	888.69	1.786	-14.7
46	484.25	6.402	-102.5	106	750.16	3.097	-31.4	166	890.47	1.771	-14.6
47	490.61	6.302	-98.4	107	753.24	3.065	-31.2	167	892.23	1.757	-14.6
48	496.86	6.205	-94.8	108	756.29	3.034	-30.9	168	893.98	1.742	-14.5
49	503.02	6.112	-91.4	109	759.31	3.003	-30.6	169	895.71	1.728	-14.5
50	509.09	6.022	-88.4	110	762.30	2.973	-30.4	170	897.44	1.713	-14.5
51	515.06	5.935	-85.7	111	765.26	2.943	-30.1	171	899.14	1.699	-14.4
52	520.96	5.851	-83.2	112	768.19	2.913	-29.9	172	900.83	1.684	-14.4
53	526.77	5.769	-81.0	113	771.08	2.883	-29.6	173	902.51	1.670	-14.4
54	532.49	5.689	-79.0	114	773.95	2.854	-29.4	174	904.17	1.655	-14.3
55	538.14	5.611	-77.1	115	776.79	2.824	-29.1	175	905.82	1.641	-14.3
56	543.72	5.534	-75.4	116	779.60	2.795	-28.8	176	907.45	1.627	-14.2
57	549.21	5.460	-73.8	117	782.38	2.767	-28.6	177	909.07	1.613	-14.2
58	554.64	5.387	-72.3	118	785.13	2.738	-28.3	178	910.68	1.599	-14.1
59	559.99	5.315	-70.9	119	787.86	2.710	-28.0	179	912.27	1.585	-14.0
60	565.27	5.245	-69.6	120	790.55	2.682	-27.7	180	913.85	1.571	-13.9

TABLE 8. *Thermocouple copper versus* Au-0.02 *at%* Fe_{45} – *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) – Continued

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
180	913.85	1.571	-13.9	240	988.94	0.988	-7.7				
181	915.41	1.557	-13.8	241	989.92	0.981	-7.5				
182	916.96	1.543	-13.7	242	990.90	0.973	-7.2				
183	918.50	1.529	-13.5	243	991.87	0.966	-6.9				
184	920.02	1.516	-13.4	244	992.83	0.960	-6.6				
185	921.53	1.503	-13.3	245	993.79	0.953	-6.3				
186	923.03	1.489	-13.1	246	994.74	0.947	-5.9				
187	924.51	1.476	-12.9	247	995.68	0.941	-5.6				
188	925.98	1.464	-12.7	248	996.62	0.936	-5.3				
189	927.44	1.451	-12.5	249	997.55	0.931	-5.0				
190	928.88	1.439	-12.3	250	998.48	0.926	-4.7				
191	930.31	1.426	-12.1	251	999.40	0.921	-4.5				
192	931.73	1.414	-11.9	252	1000.32	0.917	-4.3				
193	933.14	1.403	-11.6	253	1001.24	0.912	-4.2				
194	934.54	1.391	-11.4	254	1002.15	0.908	-4.2				
195	935.92	1.380	-11.2	255	1003.05	0.904	-4.2				
196	937.30	1.369	-10.9	256	1003.95	0.900	-4.3				
197	938.66	1.358	-10.7	257	1004.85	0.895	-4.5				
198	940.01	1.347	-10.4	258	1005.75	0.891	-4.8				
199	941.36	1.337	-10.2	259	1006.63	0.886	-5.2				
200	942.69	1.327	-9.9	260	1007.52	0.880	-5.7				
201	944.01	1.317	-9.7	261	1008.39	0.874	-6.3				
202	945.32	1.308	-9.5	262	1009.27	0.868	-6.9				
203	946.63	1.298	-9.3	263	1010.13	0.860	-7.6				
204	947.92	1.289	-9.1	264	1010.99	0.852	-8.3				
205	949.20	1.280	-8.9	265	1011.83	0.844	-9.0				
206	950.48	1.271	-8.7	266	1012.67	0.834	-9.7				
207	951.75	1.263	-8.5	267	1013.50	0.824	-10.2				
208	953.01	1.254	-8.4	268	1014.32	0.814	-10.5				
209	954.26	1.246	-8.3	269	1015.13	0.803	-10.6				
210	955.50	1.238	-8.2	270	1015.93	0.793	-10.2				
211	956.73	1.230	-8.1	271	1016.72	0.783	-9.3				
212	957.96	1.222	-8.0	272	1017.50	0.775	-7.7				
213	959.17	1.214	-8.0	273	1018.27	0.768	-5.2				
214	960.38	1.206	-7.9	274	1019.03	0.765	-1.6				
215	961.59	1.198	-7.9	275	1019.80	0.765	3.4				
216	962.78	1.190	-7.9	276	1020.57	0.772	10.0				
217	963.96	1.182	-7.9	277	1021.34	0.786	18.6				
218	965.14	1.174	-8.0	278	1022.14	0.810	29.6				
219	966.31	1.166	-8.0	279	1022.97	0.846	43.4				
220	967.47	1.158	-8.1	280	1023.84	0.898	60.5				
221	968.63	1.150	-8.1								
222	969.77	1.142	-8.2								
223	970.91	1.133	-8.3								
224	972.04	1.125	-8.4								
225	973.16	1.116	-8.5								
226	974.27	1.108	-8.6								
227	975.38	1.099	-8.6								
228	976.47	1.091	-8.7								
229	977.56	1.082	-8.7								
230	978.64	1.073	-8.8								
231	979.70	1.064	-8.8								
232	980.76	1.056	-8.8								
233	981.82	1.047	-8.8								
234	982.86	1.038	-8.7								
235	983.89	1.029	-8.6								
236	984.92	1.021	-8.5								
237	985.93	1.013	-8.4								
238	986.94	1.004	-8.2								
239	987.94	0.996	-8.0								
240	988.94	0.988	-7.7								

TABLE 9. *Thermocouple "normal" silver versus* Au-0.07 *at%* Fe_{11} *— thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	700.37	8.447	-81.3	120	1099.00	5.267	-37.0
1	7.74	8.478	1402.0	61	708.77	8.367	-79.7	121	1104.25	5.230	-36.8
2	16.88	9.774	1193.0	62	717.10	8.288	-78.2	122	1109.46	5.194	-36.5
3	27.22	10.872	1006.5	63	725.35	8.210	-76.7	123	1114.63	5.157	-36.2
4	38.57	11.794	840.7	64	733.52	8.134	-75.3	124	1119.77	5.121	-36.0
5	50.76	12.560	693.6	65	741.62	8.060	-74.0	125	1124.88	5.085	-35.7
6	63.64	13.187	563.5	66	749.64	7.986	-72.7	126	1129.94	5.050	-35.5
7	77.09	13.692	448.8	67	757.59	7.914	-71.4	127	1134.98	5.014	-35.3
8	90.99	14.089	348.0	68	765.47	7.843	-70.2	128	1139.97	4.979	-35.0
9	105.24	14.392	259.7	69	773.28	7.774	-69.1	129	1144.93	4.944	-34.8
10	119.75	14.612	182.8	70	781.02	7.705	-67.9	130	1149.86	4.910	-34.5
11	134.44	14.761	116.0	71	788.69	7.638	-66.8	131	1154.75	4.875	-34.3
12	149.25	14.847	58.4	72	796.29	7.572	-65.8	132	1159.61	4.841	-34.0
13	164.11	14.880	8.9	73	803.83	7.506	-64.7	133	1164.44	4.807	-33.8
14	178.99	14.868	-33.3	74	811.31	7.442	-63.7	134	1169.23	4.774	-33.5
15	193.84	14.816	-68.9	75	818.72	7.379	-62.7	135	1173.98	4.740	-33.3
16	208.61	14.732	-98.8	76	826.06	7.317	-61.7	136	1178.71	4.707	-33.0
17	223.29	14.620	-123.6	77	833.35	7.255	-60.8	137	1183.40	4.674	-32.8
18	237.85	14.486	-143.9	78	840.57	7.195	-59.8	138	1188.06	4.642	-32.5
19	252.26	14.333	-160.3	79	847.74	7.136	-58.9	139	1192.68	4.609	-32.3
20	266.51	14.166	-173.1	80	854.85	7.077	-58.0	140	1197.28	4.577	-32.0
21	280.59	13.988	-183.0	81	861.90	7.020	-57.1	141	1201.84	4.545	-31.7
22	294.48	13.801	-190.2	82	868.89	6.963	-56.3	142	1206.37	4.514	-31.5
23	308.19	13.608	-195.2	83	875.82	6.907	-55.4	143	1210.86	4.482	-31.2
24	321.70	13.412	-198.2	84	882.70	6.852	-54.6	144	1215.33	4.451	-31.0
25	335.01	13.213	-199.5	85	889.53	6.798	-53.8	145	1219.77	4.420	-30.7
26	348.12	13.013	-199.5	86	896.30	6.745	-53.0	146	1224.17	4.390	-30.5
27	361.03	12.814	-198.3	87	903.02	6.692	-52.2	147	1228.55	4.359	-30.3
28	373.75	12.617	-196.1	88	909.68	6.640	-51.5	148	1232.89	4.329	-30.0
29	386.27	12.422	-193.2	89	916.30	6.589	-50.7	149	1237.20	4.299	-29.8
30	398.60	12.231	-189.6	90	922.86	6.539	-50.0	150	1241.49	4.270	-29.5
31	410.73	12.043	-185.5	91	929.37	6.489	-49.3	151	1245.74	4.240	-29.3
32	422.68	11.860	-181.0	92	935.84	6.440	-48.7	152	1249.97	4.211	-29.1
33	434.45	11.681	-176.3	93	942.25	6.392	-48.0	153	1254.17	4.182	-28.8
34	446.05	11.507	-171.4	94	948.62	6.344	-47.4	154	1258.33	4.153	-28.6
35	457.47	11.338	-166.4	95	954.94	6.297	-46.8	155	1262.47	4.125	-28.4
36	468.72	11.174	-161.3	96	961.22	6.250	-46.2	156	1266.58	4.097	-28.2
37	479.82	11.016	-156.3	97	967.44	6.205	-45.6	157	1270.67	4.068	-28.0
38	490.76	10.862	-151.3	98	973.63	6.159	-45.1	158	1274.72	4.041	-27.8
39	501.54	10.713	-146.4	99	979.76	6.114	-44.6	159	1278.75	4.013	-27.6
40	512.19	10.569	-141.6	100	985.85	6.070	-44.1	160	1282.75	3.985	-27.4
41	522.68	10.430	-136.9	101	991.90	6.026	-43.6	161	1286.72	3.958	-27.2
42	533.05	10.295	-132.5	102	997.91	5.983	-43.1	162	1290.66	3.931	-27.0
43	543.28	10.165	-128.2	103	1003.87	5.940	-42.6	163	1294.58	3.904	-26.8
44	553.38	10.039	-124.1	104	1009.79	5.898	-42.2	164	1298.47	3.877	-26.6
45	563.36	9.917	-120.1	105	1015.66	5.856	-41.8	165	1302.34	3.851	-26.4
46	573.21	9.798	-116.4	106	1021.50	5.814	-41.4	166	1306.17	3.825	-26.3
47	582.95	9.684	-112.9	107	1027.29	5.773	-41.0	167	1309.98	3.798	-26.1
48	592.58	9.573	-109.5	108	1033.04	5.732	-40.6	168	1313.77	3.772	-25.9
49	602.10	9.465	-106.3	109	1038.76	5.692	-40.3	169	1317.53	3.747	-25.8
50	611.51	9.360	-103.3	110	1044.43	5.651	-39.9	170	1321.26	3.721	-25.6
51	620.82	9.258	-100.5	111	1050.06	5.612	-39.6	171	1324.97	3.695	-25.5
52	630.03	9.159	-97.9	112	1055.65	5.572	-39.3	172	1328.65	3.670	-25.3
53	639.14	9.062	-95.3	113	1061.20	5.533	-39.0	173	1332.31	3.645	-25.1
54	648.15	8.968	-93.0	114	1066.72	5.494	-38.7	174	1335.94	3.620	-25.0
55	657.08	8.876	-90.7	115	1072.19	5.456	-38.4	175	1339.55	3.595	-24.8
56	665.91	8.787	-88.6	116	1077.63	5.418	-38.1	176	1343.13	3.570	-24.7
57	674.65	8.699	-86.7	117	1083.03	5.380	-37.8	177	1346.69	3.545	-24.5
58	683.31	8.613	-84.8	118	1088.39	5.342	-37.5	178	1350.22	3.521	-24.4
59	691.88	8.529	-83.0	119	1093.71	5.304	-37.3	179	1353.73	3.497	-24.2
60	700.37	8.447	-81.3	120	1099.00	5.267	-37.0	180	1357.22	3.472	-24.1

TABLE 9. *Thermocouple "normal" silver versus* Au-0.07 *at%* Fe_{11} – *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) – Continued

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
180	1357.22	3.472	-24.1	240	1528.08	2.288	-18.2				
181	1360.68	3.448	-23.9	241	1530.36	2.270	-18.1				
182	1364.11	3.425	-23.8	242	1532.62	2.252	-18.0				
183	1367.53	3.401	-23.6	243	1534.86	2.234	-17.9				
184	1370.92	3.377	-23.4	244	1537.09	2.216	-17.7				
185	1374.28	3.354	-23.3	245	1539.29	2.198	-17.6				
186	1377.62	3.331	-23.1	246	1541.48	2.181	-17.3				
187	1380.94	3.308	-22.9	247	1543.65	2.163	-17.1				
188	1384.24	3.285	-22.8	248	1545.81	2.146	-16.8				
189	1387.51	3.262	-22.6	249	1547.95	2.130	-16.5				
190	1390.76	3.240	-22.4	250	1550.07	2.113	-16.1				
191	1393.99	3.217	-22.2	251	1552.17	2.098	-15.7				
192	1397.20	3.195	-22.0	252	1554.26	2.082	-15.3				
193	1400.38	3.173	-21.9	253	1556.34	2.067	-14.8				
194	1403.54	3.152	-21.7	254	1558.40	2.053	-14.3				
195	1406.69	3.130	-21.5	255	1560.44	2.038	-13.8				
196	1409.80	3.109	-21.3	256	1562.48	2.025	-13.2				
197	1412.90	3.087	-21.1	257	1564.49	2.012	-12.6				
198	1415.98	3.067	-20.9	258	1566.50	2.000	-12.1				
199	1419.04	3.046	-20.7	259	1568.49	1.988	-11.5				
200	1422.07	3.025	-20.5	260	1570.48	1.977	-10.9				
201	1425.09	3.005	-20.3	261	1572.45	1.966	-10.4				
202	1428.08	2.985	-20.1	262	1574.41	1.956	-9.9				
203	1431.06	2.965	-19.9	263	1576.36	1.946	-9.4				
204	1434.01	2.945	-19.7	264	1578.30	1.937	-9.1				
205	1436.94	2.925	-19.6	265	1580.23	1.928	-8.8				
206	1439.86	2.906	-19.4	266	1582.16	1.920	-8.6				
207	1442.76	2.886	-19.2	267	1584.07	1.911	-8.6				
208	1445.63	2.867	-19.0	268	1585.98	1.902	-8.7				
209	1448.49	2.848	-18.9	269	1587.88	1.893	-9.1				
210	1451.33	2.829	-18.7	270	1589.77	1.884	-9.7				
211	1454.15	2.811	-18.6	271	1591.65	1.874	-10.5				
212	1456.95	2.792	-18.5	272	1593.51	1.863	-11.7				
213	1459.73	2.774	-18.3	273	1595.37	1.851	-13.2				
214	1462.50	2.755	-18.2	274	1597.21	1.836	-15.1				
215	1465.24	2.737	-18.1	275	1599.04	1.820	-17.4				
216	1467.97	2.719	-18.0	276	1600.85	1.801	-20.2				
217	1470.68	2.701	-18.0	277	1602.64	1.780	-23.6				
218	1473.38	2.683	-17.9	278	1604.41	1.754	-27.6				
219	1476.05	2.665	-17.9	279	1606.15	1.724	-32.3				
220	1478.71	2.648	-17.8	280	1607.86	1.689	-37.7				
221	1481.34	2.630	-17.8								
222	1483.97	2.612	-17.8								
223	1486.57	2.594	-17.8								
224	1489.15	2.576	-17.8								
225	1491.72	2.559	-17.8								
226	1494.27	2.541	-17.8								
227	1496.80	2.523	-17.8								
228	1499.32	2.505	-17.9								
229	1501.81	2.487	-17.9								
230	1504.29	2.469	-18.0								
231	1506.75	2.451	-18.0								
232	1509.19	2.433	-18.1								
233	1511.62	2.415	-18.1								
234	1514.03	2.397	-18.2								
235	1516.41	2.379	-18.2								
236	1518.78	2.361	-18.2								
237	1521.13	2.342	-18.2								
238	1523.47	2.324	-18.2								
239	1525.78	2.306	-18.2								
240	1528.08	2.288	-18.2								

TABLE 10. *Thermocouple "normal" silver versus* Au-0.02 *at%* Fe_{45} — *thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T)

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
0	0.00	0.000	0.0	60	546.11	4.361	-69.2	120	727.52	2.115	-22.9
1	8.17	9.032	1624.0	61	550.44	4.293	-67.2	121	729.62	2.092	-22.7
2	17.96	10.503	1325.6	62	554.70	4.227	-65.2	122	731.70	2.069	-22.5
3	29.08	11.695	1063.4	63	558.89	4.163	-63.3	123	733.76	2.047	-22.3
4	41.27	12.641	833.7	64	563.02	4.100	-61.6	124	735.80	2.025	-22.0
5	54.29	13.372	633.5	65	567.09	4.039	-59.9	125	737.81	2.003	-21.8
6	67.95	13.917	459.6	66	571.10	3.980	-58.4	126	739.80	1.981	-21.6
7	82.07	14.299	309.5	67	575.05	3.923	-56.9	127	741.77	1.960	-21.3
8	96.50	14.543	180.6	68	578.95	3.867	-55.4	128	743.72	1.939	-21.1
9	111.11	14.667	70.7	69	582.79	3.812	-54.0	129	745.65	1.918	-20.8
10	125.80	14.690	-22.4	70	586.57	3.758	-52.7	130	747.56	1.897	-20.6
11	140.46	14.627	-100.5	71	590.30	3.706	-51.4	131	749.44	1.876	-20.3
12	155.03	14.493	-165.3	72	593.98	3.656	-50.1	132	751.31	1.856	-20.1
13	169.43	14.300	-218.4	73	597.61	3.606	-48.9	133	753.16	1.836	-19.8
14	183.61	14.060	-261.2	74	601.20	3.558	-47.8	134	754.98	1.817	-19.5
15	197.54	13.781	-294.9	75	604.73	3.511	-46.6	135	756.79	1.797	-19.3
16	211.17	13.473	-320.8	76	608.22	3.465	-45.5	136	758.58	1.778	-19.0
17	224.48	13.142	-339.9	77	611.66	3.420	-44.4	137	760.35	1.759	-18.7
18	237.45	12.795	-353.1	78	615.06	3.376	-43.4	138	762.10	1.741	-18.5
19	250.06	12.437	-361.2	79	618.41	3.333	-42.4	139	763.83	1.722	-18.2
20	262.32	12.074	-365.1	80	621.72	3.291	-41.4	140	765.54	1.704	-17.9
21	274.21	11.708	-365.3	81	624.99	3.250	-40.4	141	767.24	1.686	-17.7
22	285.73	11.344	-362.5	82	628.22	3.210	-39.5	142	768.91	1.669	-17.4
23	296.90	10.984	-357.1	83	631.41	3.171	-38.6	143	770.57	1.652	-17.2
24	307.70	10.630	-349.8	84	634.57	3.133	-37.7	144	772.22	1.635	-16.9
25	318.16	10.285	-340.8	85	637.68	3.095	-36.9	145	773.84	1.618	-16.7
26	328.28	9.949	-330.5	86	640.76	3.059	-36.1	146	775.45	1.601	-16.4
27	338.06	9.624	-319.3	87	643.80	3.023	-35.3	147	777.05	1.585	-16.2
28	347.53	9.311	-307.4	88	646.80	2.988	-34.6	148	778.62	1.569	-16.0
29	356.69	9.010	-295.0	89	649.77	2.954	-33.9	149	780.18	1.553	-15.8
30	365.55	8.721	-282.4	90	652.71	2.921	-33.2	150	781.73	1.537	-15.6
31	374.14	8.445	-269.7	91	655.62	2.888	-32.5	151	783.26	1.522	-15.4
32	382.45	8.182	-257.0	92	658.49	2.856	-31.9	152	784.77	1.507	-15.2
33	390.50	7.931	-244.6	93	661.33	2.824	-31.3	153	786.27	1.491	-15.0
34	398.31	7.692	-232.4	94	664.14	2.793	-30.7	154	787.75	1.476	-14.9
35	405.89	7.466	-220.5	95	666.91	2.762	-30.2	155	789.22	1.462	-14.7
36	413.25	7.251	-209.1	96	669.66	2.733	-29.7	156	790.68	1.447	-14.6
37	420.40	7.048	-198.1	97	672.38	2.703	-29.2	157	792.12	1.433	-14.4
38	427.35	6.855	-187.6	98	675.07	2.674	-28.8	158	793.54	1.418	-14.3
39	434.11	6.672	-177.6	99	677.73	2.646	-28.3	159	794.95	1.404	-14.2
40	440.70	6.499	-168.2	100	680.36	2.617	-27.9	160	796.35	1.390	-14.1
41	447.11	6.336	-159.2	101	682.96	2.590	-27.6	161	797.73	1.376	-14.0
42	453.37	6.181	-150.8	102	685.54	2.562	-27.2	162	799.10	1.362	-13.9
43	459.48	6.034	-143.0	103	688.09	2.535	-26.9	163	800.46	1.348	-13.8
44	465.44	5.895	-135.6	104	690.61	2.508	-26.6	164	801.80	1.334	-13.8
45	471.27	5.763	-128.7	105	693.10	2.482	-26.3	165	803.13	1.320	-13.7
46	476.97	5.637	-122.3	106	695.57	2.456	-26.0	166	804.44	1.307	-13.7
47	482.55	5.518	-116.4	107	698.02	2.430	-25.7	167	805.74	1.293	-13.6
48	488.01	5.404	-110.9	108	700.43	2.404	-25.5	168	807.03	1.279	-13.6
49	493.36	5.296	-105.7	109	702.82	2.379	-25.2	169	808.30	1.266	-13.5
50	498.60	5.193	-101.0	110	705.19	2.354	-25.0	170	809.56	1.252	-13.5
51	503.74	5.094	-96.6	111	707.53	2.329	-24.8	171	810.80	1.239	-13.4
52	508.79	4.999	-92.6	112	709.85	2.305	-24.5	172	812.04	1.226	-13.4
53	513.74	4.909	-88.8	113	712.14	2.280	-24.3	173	813.25	1.212	-13.4
54	518.61	4.822	-85.4	114	714.41	2.256	-24.1	174	814.46	1.199	-13.3
55	523.39	4.738	-82.2	115	716.65	2.232	-23.9	175	815.65	1.186	-13.3
56	528.09	4.657	-79.2	116	718.87	2.208	-23.7	176	816.83	1.172	-13.2
57	532.70	4.579	-76.4	117	721.07	2.184	-23.5	177	818.00	1.159	-13.2
58	537.25	4.504	-73.9	118	723.24	2.161	-23.3	178	819.15	1.146	-13.2
59	541.71	4.432	-71.5	119	725.39	2.138	-23.1	179	820.29	1.133	-13.1
60	546.11	4.361	-69.2	120	727.52	2.115	-22.9	180	821.41	1.120	-13.0

TABLE 10. *Thermocouple "normal" silver versus Au-0.02 at% Fe45 — thermoelectric voltage, Seebeck coefficient, and derivative of the Seebeck coefficient;* E = f(T) — Continued

T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²	T K	E μV	S μV/K	dS/dT nV/K²
180	821.41	1.120	-13.0	240	869.29	0.524	-8.6				
181	822.53	1.107	-13.0	241	869.81	0.516	-8.5				
182	823.63	1.094	-12.9	242	870.32	0.507	-8.4				
183	824.71	1.081	-12.8	243	870.82	0.499	-8.2				
184	825.79	1.068	-12.7	244	871.32	0.491	-8.0				
185	826.85	1.055	-12.6	245	871.80	0.483	-7.9				
186	827.90	1.043	-12.5	246	872.28	0.475	-7.7				
187	828.94	1.030	-12.4	247	872.75	0.468	-7.5				
188	829.96	1.018	-12.3	248	873.22	0.460	-7.3				
189	830.97	1.006	-12.2	249	873.68	0.453	-7.1				
190	831.97	0.994	-12.1	250	874.12	0.446	-6.8				
191	832.96	0.982	-11.9	251	874.57	0.439	-6.6				
192	833.94	0.970	-11.8	252	875.00	0.433	-6.5				
193	834.90	0.958	-11.6	253	875.43	0.426	-6.3				
194	835.85	0.946	-11.5	254	875.86	0.420	-6.1				
195	836.79	0.935	-11.3	255	876.27	0.414	-6.0				
196	837.72	0.924	-11.1	256	876.68	0.408	-5.9				
197	838.64	0.913	-11.0	257	877.09	0.402	-5.9				
198	839.55	0.902	-10.8	258	877.49	0.396	-5.8				
199	840.44	0.891	-10.6	259	877.88	0.391	-5.9				
200	841.33	0.881	-10.4	260	878.27	0.385	-6.0				
201	842.20	0.870	-10.3	261	878.65	0.379	-6.1				
202	843.07	0.860	-10.1	262	879.03	0.372	-6.3				
203	843.93	0.850	-9.9	263	879.40	0.366	-6.5				
204	844.77	0.840	-9.8	264	879.76	0.359	-6.8				
205	845.61	0.831	-9.6	265	880.12	0.353	-7.1				
206	846.43	0.821	-9.5	266	880.46	0.345	-7.4				
207	847.25	0.812	-9.3	267	880.81	0.338	-7.7				
208	848.05	0.802	-9.2	268	881.14	0.330	-7.9				
209	848.85	0.793	-9.1	269	881.47	0.322	-8.1				
210	849.64	0.784	-8.9	270	881.78	0.314	-8.2				
211	850.42	0.775	-8.8	271	882.09	0.305	-8.2				
212	851.19	0.767	-8.7	272	882.39	0.297	-7.9				
213	851.95	0.758	-8.7	273	882.69	0.290	-7.3				
214	852.71	0.749	-8.6	274	882.97	0.283	-6.3				
215	853.45	0.741	-8.5	275	883.25	0.277	-4.8				
216	854.19	0.732	-8.5	276	883.53	0.274	-2.7				
217	854.92	0.724	-8.5	277	883.80	0.272	0.2				
218	855.64	0.715	-8.4	278	884.08	0.274	4.0				
219	856.35	0.707	-8.4	279	884.35	0.281	9.0				
220	857.05	0.698	-8.4	280	884.64	0.293	15.3				
221	857.74	0.690	-8.5								
222	858.43	0.681	-8.5								
223	859.11	0.673	-8.5								
224	859.78	0.664	-8.5								
225	860.44	0.656	-8.6								
226	861.09	0.647	-8.6								
227	861.73	0.639	-8.7								
228	862.36	0.630	-8.7								
229	862.99	0.621	-8.8								
230	863.61	0.612	-8.8								
231	864.22	0.604	-8.8								
232	864.81	0.595	-8.9								
233	865.40	0.586	-8.9								
234	865.99	0.577	-8.9								
235	866.56	0.568	-8.9								
236	867.12	0.559	-8.9								
237	867.68	0.550	-8.8								
238	868.22	0.542	-8.8								
239	868.76	0.533	-8.7								
240	869.29	0.524	-8.6								

459-033 OL - 72 - 7

scales used. Units for the thermocouple tables and functions are based on the "NBS as-maintained volt" [12]; the International Practical Temperature Scale, IPTS–68, [13, 14, 15] for temperature above 20 kelvin; and the NBS acoustical scale, P 2–20 (1965), [16, 17] for temperatures between 4 and 20 kelvin.

TABLE 11. *Total uncertainties in thermocouple calibrations*

Thermocouple combination	Total uncertainty		
	4–20 K	20–75 K	75–280 K
KP vs Au-0.07 at% Fe..............	9.8 mK	11.3 mK	31.9 mK
KP vs Au-0.02 at% Fe..............	14.2	16.1	33.1
Cu vs Au-0.07 at% Fe..............	17.1	20.1	54.7
Cu vs Au-0.02 at% Fe..............	14.4	22.8	81.4
n.Ag vs Au-0.07 at% Fe.............	16.2	19.9	59.1
n.Ag vs Au-0.02 at% Fe.............	14.3	23.5	84.8

5. Discussion

It is apparent from figure 4 that the Au-0.07 at% Fe_{47} alloy, used in the first calibration, has a lower Seebeck coefficient than all but one of the specimens tested in the second calibration. A possible reason for the lower thermopower is suggested by comparison with Rosenbaum's data in figure 6. The Seebeck coefficient for specimen 47 falls below that of Rosenbaum's annealed sample results by 4.7 percent at 20 K. This is in the right direction and appears to be of a reasonable magnitude to be caused by underannealing or annealing at a high temperature in the presence of oxygen. Oxygen combines with iron which, in effect, removes the iron from the transport processes which are responsible for the high thermopower of the dilute alloys [18]. Regardless of the reason for the lower sensitivity the fact remains that specimen 47 should not be chosen to represent the alloy in light of the information from the specimens used in the second calibration. The data shown in figures 3 and 4 indicate that the specimens 8, 10, or 11 would have the general properties desired and have a sensitivity near the average of the materials tested. The choice among these three wires is rather arbitrary and perhaps unimportant since, in general, published tables must be adjusted to the particular thermocouple wires being used. The important consideration is that the published data can be adjusted to fit any particular working thermocouple of this type.

The "normal" silver and copper versus Au-0.07 at% Fe_{11} data presented in this paper were calculated since neither "normal" silver nor copper were included in the second calibration with Au-0.07 at% Fe_{11}. The following relationships were used to arrive at "normal" silver and copper versus Au-0.07 at% Fe_{11}:

$$E(\text{Cu vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) - E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) + E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11}) = E(\text{Cu vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11})$$

$$E(\text{n. Ag vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) - E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) + E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11}) = E(\text{n. Ag vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11})$$

The actual combination was accomplished by combining the power series coefficients, e.g.,

$$E(\text{Cu vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) = A_1 + A_2T + A_3T^2 + \ldots \equiv E_A$$

$$+$$

$$E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11}) = B_1 + B_2T + B_3T^2 + \ldots \equiv E_B$$

$$-$$

$$E(\text{KP vs } \underline{\text{Au}}\ 7\ \text{Fe}_{47}) = C_1 + C_2T + C_3T^2 + \ldots \equiv E_C$$

$$E(\text{Cu vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11}) = (A_1 + B_1 - C_1) + (A_2 + B_2 - C_2)T + (A_3 + B_3 - C_3)T^2 + \ldots$$

The uncertainty in the calculated tables will be the combination of uncertainties, e.g.,

$$\sigma_{\text{Cu vs } \underline{\text{Au}}\ 7\ \text{Fe}_{11}} = [\sigma^2(E_A) + \sigma^2(E_B) + \sigma^2(E_C)]^{1/2}.$$

The selection of the Au-0.02 at% Fe specimen to be reported in detail is not as difficult as was the Au-0.07 at% Fe, primarily because we have only two specimens to consider. Figures 7 and 9 indicate that our Au-0.02 at% Fe_{45} is probably nearer to the optimum anneal than is the later specimen 12. Specimen 45 was used in the first calibration and was compared directly to both copper and "normal" silver. This eliminates the need to combine coefficients and increase the uncertainty as was the case for Au-0.07 at% Fe.

Mr. W. J. Hall was largely responsible for the computer programs used to fit the experimental data. Mr. Ed Zysk of Engelhard Industries and the late Dr. Bert Brenner of Sigmund Cohn Corporation were extremely cooperative in producing and supplying the Au-Fe test wire.

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(Paper 76A3–721)